THE UNIVERSITY OF ALBERTA

PHYTOPLANKTON SUCCESSION IN ASTOTIN LAKE,

ELK ISLAND NATIONAL PARK, ALBERTA

by

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The undersigned certify that they have read and
recommended to the Faculty of Graduate Studies for
acceptance, a thesis entitled PHYTOPLANKTON SUCCESSION IN
ASTOTIN LAKE, ELK ISLAND NATIONAL PARK, ALBERTA, submitted
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ments for the degree of Master of Science.

ABSTRACT

The present investigation took place between mid-May of 1966 and early September of 1967 with particular attention to the ice free seasons. Astotin Lake is a typical eutrophic, kettle lake with shallow, landlocked, hard water. High concentrations of nutrients in Astotin Lake supported a large standing crop from the spring through the autumn. The intense summer blooms were caused by *Anabaena* spp., *Aphanizomenon flos-aquae* and *Microcystis aeruginosa*. The spring and autumnal maxima were dominated by diatoms such as *Asterionella formosa*, *Melosira italica* and *Cyclotella meneghiniana*. It was found that most of the green algae were inhibited by these blooms of blue-green algae. For example, green algae were present in very small numbers during the *Anabaena* bloom but flourished subsequent to the disappearance of the *Anabaena* bloom. A few species of the Scenedesmaceae and the Oocystaceae, especially *Scenedesmus quadricauda*, were relatively compatible with these summer blooms.

The variation in species composition and production of phytoplankton in 1966 and 1967 is thought to be associated with the treatment of the lake by copper sulfate in 1964 and 1965. During 1967, the diatom-dominated spring and autumn maxima were much greater and summer blooms were more intensive than those of 1966. *Asterionella formosa* dominated the spring maximum in 1966, while in 1967 *Cyclotella meneghiniana* appeared as the vernal dominant. *Dinobryon sertularia* and *Gloeotrichia echinulata* were found locally distributed in this lake. The spatial variation of most of the planktonic algae of Astotin

Lake was affected by prevailing wind to a great extent.

Data on the physical, chemical and biotic features are presented and the results of the study of these environmental conditions are applied to the discussion of the phytoplankton succession. Deficiency of silica concentration causes the decline of the spring maximum of diatoms, such as *Asterionella formosa* in 1966 and *Cyclotella meneghiniana* in 1967. Relatively high water temperature during the summer favors the blue-green algal bloom and results in high concentrations of organic matter. The decomposition of dead *Anabaena* cells probably released certain kinds of extracellular substances which affected the succession of subsequent phytoplankton communities to a great extent.

Although the succession and periodicity of the phytoplankton have been extensively investigated, the phases of these planktonic algae during their off season, i.e. the dormant state between seasonal and annual cycles is largely unknown. The results of the present study are compared with other investigations on phytoplankton flora, especially the development of blue-green algal blooms in similar geographical regions.

The measures dealing with controlling the excessive blue-green algal growth are discussed. Evaluation and reduction of the essential nutrients which may be limiting to the growth of blue-green algae in advanced eutrophicated waters should be the prime objectives in controlling algal blooms.

ACKNOWLEDGMENTS

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INTRODUCTION

The study of the phytoplankton has long been one
of the central subjects of limnological research and the
explanation of the factors controlling the periodicity,
regional distribution and community succession of the phy-
toplankton has been the subject of many investigations.
The study of this microscopic floating plant life has
recently been stimulated by an awareness of the economic
importance of their growth in the environment. One of the
most important primary producers in many inland aquatic
ecosystems is the phytoplankton. However, the excessive
growth of many planktonic species upsets the ecosystems in
which such growth occurs.

A great number of freshwater bodies have been
enriched with organic and inorganic substances by natural
agents   such as wild water fowl, nitrogen fixation by
either bacteria or blue-green algae and precipitation.
This process of enrichment of impounded water is called
natural eutrophication. Where the enrichment is the
result of human activities, for example inflow of farm-
land fertilizer, effluent of sewage and industrial waste,
the process is termed artificial eutrophication. Increase
in standing crop of phytoplankton is one of the most con-
spicuous consequences of eutrophication of lakes and often
it results in severe cases of waterbloom caused by the
blue-green algae. The complex relations between algal

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blooms and environmental conditions are still only partially
understood. Many specific nutrients have been considered to
be the cause of blue-green algal blooms and greatest atten-
tion has been paid to nitrogen and phosphorus as the most
common limiting factors for the occurrence of these blooms.
Careful studies of nutrient requirements for bloom-forming
algae have been limited to investigations on some inorganic
elements such as iron, manganese, phosphorus, nitrogen. As
far as the requirements of organic nutrients are concerned,
they are still largely unknown.

From an ecological point of view, the event of
algal blooms in the natural waters has been observed and
fully described. But the causes of algal bloom sequences
in phytoplankton seasonal succession, and the features of
the resting stages or the phase between blooms are serious
deficiencies in our knowledge.

Astotin Lake has been investigated sporadically
during the past thirty years in regard to its use for
recreation purposes. Brief investigations were done by Dr.
D. S. Rawson and Dr. N. M. Rogers in 1936 and 1940, res-
pectively. They reported that a large amount of organic
matter in the lake, and long periods of ice cover during
the winter caused severe winter stagnation. A determination
of dissolved oxygen during March 1941 indicated a concentra-
tion of only 0.5 ppm. According to Dr. Solman's investi-
gation of 1946, the deepest area of water was recorded as
19½ feet. However, the latest sounding contours, which

were done by Leslie Uhazy in 1966, indicated that a small
area of water was between 20 and 23 feet deep.

The blue green algae in Astotin Lake began rapid
growth in 1934 and their first bloom was noticed in 1936
(Solman 1946). Absence of concurrent limnological data
leaves the explanation for this phenomenon of bloom forma-
tion unknown. There is no record of what critical changes
took place in the lake before 1936. However, records in-
dicate that from 1929 to 1933 there was no outflow from
Astotin Lake. This condition of stagnancy undoubtedly
would have caused an increase in the concentration of dis-
solved solids in the water, and this increase may have
induced a suitable environment for the growth of great popu-
lations of blue green algae. During 1936, Dr. Rawson found
that the algal bloom was composed mainly of blue green
algae of the genus *Aphanizomenon*. During 1946 the bloom
was composed largely of cells of the genus *Anabaena* with
relatively smaller numbers of cells of the genus *Nodularia*
and *Microcystis*. No colonies of *Aphanizomenon* were noted
but blooms of this species may have occurred at some other
time during the season. The bloom genera during the 1958
season were *Anabaena* and *Aphanizomenon* (Carefoot 1959). I
presume that these variations in composition of the blue
green algal blooms reported by these previous investigators
may be due to the disregard of seasonal periodicity.

Besides the algal flora, a considerable change
in the fauna was reported in Astotin Lake. According to

records available, pike and suckers were present in great
numbers until the spring of 1933 during which year hundreds
of dead fish were washed out along the shore of Astotin Lake.
The fish fauna was eliminated by the winter-kill of 1933,
and no sign of sport fish has been noticed in the lake since
that time.

Apparently the year of 1933 has its significance
in the chronicle of Astotin Lake. During 1932, a dam was
established at a distance of several miles down Martin Creek,
(Figure 5, page 43) which used to drain Astotin Lake into
the North Saskatchewan River. The construction of the dam
prevented the flow of water down Martin Creek and the fish
spawning migration in the spring season from the North Sas-
katchewan River to the Lake became obstructed. Simultane-
ously, the prevention of drainage made the lake more eutro-
phic and was probably responsible for both summer and winter
fish kill.

Consequently, in Dr. Rawson's report of 1936 the
use of copper sulfate was recommended for the control of the
algal bloom. Copper sulfate was used annually from 1936 to
1947 and was applied again during 1957 and 1958 after ten
years of disuse. Recently, Plowman investigated Astotin
Lake during 1962 and recommended a mixed algicide consisting
of copper sulfate, phygon, and bentonite. This mixed algi-
cide was applied during 1964 and 1965.

The present study was an investigation of the
growth of the phytoplankton in Astotin Lake, Elk Island

National Park, Alberta, with special attention to the summer
period when water blooms occurred. There were two main objec-
tives in this investigation. The first objective was to ob-
tain information on the species composition, community suc-
cession, periodicity and spatial variation of the phytoplank-
ton. The second objective was to study some of the limnolo-
gical characteristics which were considered to be related to
the development of the phytoplankton.

LITERATURE REVIEW

Since Thienemann and Naumann proposed the first
division of lakes into oligotrophic and eutrophic types, many
additional lake types have been described. Originally, the
quantity of organisms produced served as the basis for this
classification. Naumann's system (Hutchinson 1967) defined
certain phytoplanktonic forms as characteristic of eutrophic
or oligotrophic lakes. Hutchinson (1967) commented on
Naumann's scheme as follows, "This classification may now
appear incomplete and a little naïve, there is no doubt that
it embodies a good deal of truth." When we apply Naumann's
scheme to Pearsall's work in the English Lake District
(1921, 1932), clearly, we may regard these English lakes as
oligotrophic and typical desmid types. However, *Melosira*,
which is considered to be an eutrophic organism, and blue-
green algal species such as *Oscillatoria* appear in some of
the lakes of this region. Furthermore, the most important
eutrophic diatom *Asterionella*, which does not figure in
Naumann's scheme, also grew in these lakes.

Many investigations of inland waters carried out
in various geographical regions used the dominant species
of phytoplankton as indicators of the trophic types of those
waters. However, Rawson (1956) pointed out that the domin-
ant species of planktonic algae in the Great Lakes and in
the large lakes of Western Canada were not those commonly
cited as oligotrophic indicators. A similar case was also

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found in certain small shallow lakes in Central Alberta
(Bozniak 1966). This discrepancy in using phytoplankton spe-
cies as trophic indicators may be due to the lack of detailed
taxonomic information, or to the non-existence of oligotro-
phic and eutrophic indicators.

In many year-round investigations of various lakes,
the phytoplankton production has shown two major annual
pulses, one in early spring and the other in the late fall
(Chandler and Weeks 1945, Davis 1954, 1962). This pattern
of phytoplankton periodicity is exhibited in large temperate
lakes in which the nutrient supply in epilimnial water is
closely related to vernal and autumnal circulation. Pennak
(1946) who investigated seven small Colorado lakes, reported,
"Only one showed characteristic spring and autumn pulses.
Another lake had three pulses one in spring, one in mid-
summer and one in autumn. Each of the other four lakes had
only a single peak in the annual population curve; in three
of these it occurred sometimes during the spring, and in the
other during the summer." Evidently, the seasonal develop-
ment of phytoplankton in these shallow lakes is not regu-
lated by the nutrients which are replenished by the spring
and autumnal water circulation.

In reviewing the literature dealing with the fac-
tors influencing the development and decline of phytoplank-
ton pulses, one must consider the seasonal changes in water
temperature, in solar radiation and in the concentration of
nutrients. McCombie (1953) stated, "The growth of

phytoplankton is influenced by factors of supply (limiting factors) and factors of control. Among the limiting factors are the intensity of light and duration of illumination which govern the supply of energy for photosynthesis, and the concentration of nutrient elements which constitute the structural units of carbohydrates. Temperature, ionic balance, concentration of catalysts, and probably pH may be controlling factors which determine the rate at which the phytoplankton can exploit the limiting factors."

The spring maximum in temperate water is a well known feature of phytoplankton development. In his studies of phytoplankton in some central Swedish lakes Willén (1962) stated, "The change from ice covered lakes to open water is the critical time in the succession and development of phytoplankton. During the vernal water circulation after the breaking up of the ice more suitable temperature, light, oxygen and nutrient conditions occur and an increase in the standing crop was recorded in all lakes." However, since the nutrients in temperate waters may reach their maximum levels by mid-winter (Fogg 1965) the physical conditions of light and temperature must be chiefly responsible for the spring pulse. Lund et al (1963) found that *Asterionella* grew vigorously during the winter but did not develop its maximum numbers until the spring. This suggests that light and temperature are limiting factors during the winter.

Several factors are considered to be the cause of the decline of the spring maximum. One of these factors is

the dense growth of the phytoplankton which decreases the light penetration by self-shading (Talling 1960b). Generally, the deficiency of a mineral nutrient is expected to be one of the most important factors causing the decline of phytoplankton growth. This nutrient depletion in the epilimnion normally extends over a period of two months or so in temperate lakes when the standing crop of phytoplankton remains at a relatively low and steady level (Fogg 1965). Golterman (1960) on the other hand, considered that the decline of spring diatom pulse is caused by the increasing water temperature in early summer.

A great number of investigations have focused on the relationship between the abundance of the phytoplankton and their chemical environment. Chu (1942) described the importance of nitrate and phosphate in his cultures as follows, "The requirements of N and P agree well among the different planktonic algae and the algae are likely to suffer from a deficiency when the concentration of N is below 0.2 mg/l and that of P below 0.05 mg/l." Prescott (1939) found there was a positive correlation between phosphorus content and productivity of phytoplankton in Iowa Lakes. In some of the Wisconsin Lakes, however, there was no evidence that phosphorus was a limiting factor to growth of phytoplankton populations (Juday et al 1928). After intensive investigations of certain lakes in Michigan, Tucker (1957) also found that the fluctuation of soluble inorganic phosphate in the epilimnial water seemed to have no relationship

to the occurrence of spring and fall phytoplankton pulses.
Many investigators have thought that the level of nitrates is
a controlling factor in phytoplankton growth cycles. Pres-
cott (1939) who has carried out studies of phytoplankton in
the field and in the laboratory pointed out that there is a
direct correlation between nitrogen and phytoplankton quan-
tity in both environments. Pearsall (1932) Cooper (1937)
and Hutchinson (1941) postulate that changes in the ratio
of nitrates to phosphates may be responsible for differences
in the magnitudes of the phytoplankton populations.

Pearsall (1932) concluded that in the English
lakes, diatoms occur when the waters are richest in nitrate,
phosphate and silica. He also reported that diatoms cannot
reproduce appreciably when the concentration of silica is
less than 0.5 mg/l. Lund (1950) confirmed Pearsall's con-
clusion in the case of silica, but disagreed about the
phosphate. However, Hutchinson (1944) found the water of
Linsley Pond adequately supplied with phosphorus, nitrogen
and silica but poor in diatoms and therefore doubted
Pearsall's hypothesis. The regeneration of silica content
in natural water by the decomposition of diatom cells is
responsible for the succession of diatoms according to
Jørgenson (1957). Very little work has been done on the
chemical factors influencing the green algae in natural
waters. Pearsall (1932) concluded that more green algae
occur during periods when concentrations of nitrates and
phosphate are low; desmids, in particular, occur when

calcium and the N/P ratio is low. He further states that in
the English lakes there seems to be no general correlation
between abundance of green algae and the amount of organic
matter. Duthie (1965) reported recently that the Chlorophy-
ceae, flagellates and diatoms are favoured by high organic
matter in the lake. Rhode (1948) found that the concentra-
tion of inorganic salts, for instance iron, had a signifi-
cant influence on various species of planktonic green algae
in his laboratory cultures.

Recently the production of extra cellular organic
substances in both nature and in culture has been suggested
as either a growth-promoting or growth-inhibiting factor in
phytoplankton development (Hodgetts 1922, Akehust 1931,
Jørgensen 1957, Proctor 1957, Vance 1965). Fogg (1965)
stated that the extracellular substances may be produced by
specific organisms and may have specific effects on parti-
cular species, so that their role in interspecific competi-
tion and determination of the qualitative composition of
the phytoplankton may be important. He also pointed out
that the biologically active substances can be liberated
either during healthy growth or after the death of the
cells. Evidence for the production of growth promoting
substances by algae in culture has been found by many
workers. Bentley (1958, 1960) found that the extracts of
Chlorella and various plankton algae, the filtrates from
cultures of *Anabaena cylindrica* and filtrates from lake
water containing a nearly unialgal growth of *Oscillatoria*

species, contained plant hormones of the auxin type. On the
other hand, a great number of publications have reported that
certain species inhibit the growth of others in mixed cul-
ture. Proctor (1957) showed that inhibition of *Haematococcus*
pluvialis by *Chlamydomonas reinhardtii* is caused by a fatty
acid liberated from the dead *Chlamydomonas* cells. However,
Talling (1957b) found no evidence of production of extra-
cellular substances which appreciably modified the growth
of *Asterionella formosa* and *Fragilaria crontonensis* in mixed
culture. Vance (1965) studied blue-green algal blooms in
Missouri ponds and he pointed out that the results suggest
that certain kinds of unrecognized active metabolites
liberated by blue-green algae may be important in control-
ling species succession and species dominance within a
given phytoplankton population. After his extensive
research on extracellular products of algae in both culture
and freshwater (Fogg 1952, Fogg and Westlake 1955, Fogg
and Boalch 1958, Fogg and Miller 1958) Fogg commented, "It
is attractive to explain succession in terms of traces of
biologically active substances, but clearly it is still not
possible to say whether or not this is an important factor."

The formation of water blooms is a phenomenon
caused by excessive growth of planktonic algae. Many dif-
ferent genera of algae have been found to form blooms all
over the world. In an intensive investigation in the United
States Palmer (1964) reported that the blooms were caused
by no less than 20 genera which belong to the Cyanophyceae,

Chlorophyceae and Bacillariophyceae. The bloom-producing spe-
cies in the lakes of the Canadian prairie provinces are chief-
ly species of *Anabaena*, *Aphanizomenon* and *Microcystis* (Hammer
1964, Bozniak 1966, Pinsent 1967). Billaud (1967) found that
the intensive water blooms occurring during the summer in
Alaskan shallow lakes were also caused by blue-green algae
namely, species of *Anabaena* and *Aphanizomenon*.

Many environmental factors may influence the
development, the duration and the decline of blue-green
algal blooms and these factors have been the subject of a
great deal of research. Fitzgerald (1964) pointed out that,
"The subject is so diverse that it cannot be dealt with on
a simple fact-to-fact basis, but requires information from
a great many fields of interest in order that a very general
understanding of a very complex system can be evolved." The
view that the important cause of blue-green algal blooms is
the available supply of nutrients has lead to many investi-
gations designed to collect information about nutrients in
the water. From an extensive ecological investigation of
bloom-forming algae such as species of *Microcystis*, *Anabaena*
and *Aphanizomenon* in Saskatchewan lakes, Hammer (1965) con-
cluded that in relation to variations in salinity of the
water these algae were widely distributed, but that they
formed blooms over a much narrower salinity range. *Anabaena*
flos-aquae occurred in salinities ranging from 27 to 40,359
ppm, but bloomed in a narrower range of 423 to 7,275 ppm;
Aphanizomenon flos-aquae occurred in a narrower range

(27 - 7,275 ppm) of salinity and bloomed in the range 226 -
7,275 ppm; *Microcystis aeruginosa* occurred in a range of 167 -
40,359 ppm and bloomed in the 630 - 7,275 ppm range. Gerloff
et al (1952) showed that the bloom-forming blue-green algae
can be grown in pure mineral media without organic additives.
In further culture experiments Gerloff (1957) found that the
growth of *Microcystis aeruginosa* was inhibited by high con-
centrations of manganese ion and that this toxic level of
manganese was affected by the calcium concentration in the
culture medium. Therefore, in the natural waters, the inhi-
bition level of manganese to *Microcystis aeruginosa* may vary
with the variation in the concentration of calcium in those
waters. Nitrogen and phosphorus generally have been con-
sidered the nutrient elements most likely to limit the
development of algal blooms. Widely quoted figures are
given by Sawyer (1947) who said, "The data regarding criti-
cal levels of inorganic phosphorus are much more decisive
and indicate that nuisance conditions can be expected when
the concentration of inorganic phosphorus exceeds or equals
0.01 ppm." He notes further that, "The importance of nit-
rogen in supporting algal blooms cannot be denied. A cri-
tical level of 0.30 ppm of inorganic forms is indicated from
the data obtained. However, it should be pointed out that
extensive algal growths were produced under laboratory con-
ditions with plentiful supplies of phosphorus and deficient
supplies of nitrogen. Undoubtedly, nitrogen fixation,
either bacterial or algal, bridges the deficiency and

produces the nitrogen necessary for the synthesis of algal protein." Gerloff (1957a) stated that under controlled culture conditions, nitrogen is much more critical than either phosphorus or iron for the growth of *Microcystis aeruginosa*, a species unable to fix atmospheric nitrogen. Many investigations suggest that nitrogen fixation by blue-green algae that develop water blooms (Krauss 1958, Dugdale and Neess 1961, Dugdale et al 1964, Dugdale and Dugdale 1962, 1965) and the recycling of nitrogen by disintegration of these algae (Grill and Richards 1964) play an important and complex part in the development of waterblooms.

Billaud (1967) reported that a bloom of *Anabaena* during low nitrogen concentration following impoundment was followed by a bloom of *Aphanizomenon* in which, apparently, the nitrate regenerated from the nitrogen fixed by the initial population of blue-green algae was being used. This result supports the report of Prowse and Talling (1958) about work done on a reservoir in the White Nile which indicated that the growth of *Anabaena* is important in determining the seasonal succession of phytoplankton. In the waters with direct effluent of sewage or other organic pollutants the algal blooms may be dominated by species of *Microcystis*, *Aphanizomenon* or other non-nitrogen fixing members through the entire season (Fitzgerald 1964). This work suggests that organic nitrogen may play a key role in development of an algal bloom and the sequence of species involved.

Besides the nutrient factors mentioned above,

water blooms have always been found in hard waters with a
high pH. Prescott (1961) found in the southern Wisconsin and
Michigan region, that luxuriant water blooms occurred in
numerous lakes of which the drainage systems were generally
high in calcium and half-bound CO_2 and had a high pH (7.2 -
9.4). Theoretically, the excessive growth of planktonic
algae only occurs in waters which are amply supplied with
free CO_2 or with half-bound CO_2 (bicarbonate) from which CO_2,
necessary for photosynthesis, can be withdrawn. Hence, hard,
alkaline lakes support blooms.

Some physical conditions of the environment, such
as water temperature and lake morphometry have been con-
sidered to be important factors in water bloom development.
Temperature often influences the time of appearance and the
sequence of bloom formation in natural waters. According to
his investigations, Hammer (1964) found that *Anabaena flos-
aquae* was present after the water reached 5°C and that bloom
formation usually occurred when water temperatures were 15° -
20°C. *Aphanizomenon flos-aquae* was rarely present until the
temperature rose to about 20°C and the blooms appeared dur-
ing a range of 22.5° - 26.5°C. *Microcystis aeruginosa*
exhibited tolerance to a wide range of temperatures from 0°C
under the ice to 26°C and most blooms appeared at tempera-
tures above 20°C. Gorham (personal communication 1967)
reported that bloom-forming algae in laboratory culture are
capable of anaerobic growth. Hence there may be consider-
able development on the bottom during the ice-covered season.

However, to my knowledge, there is no record in the litera-
ture of the critical temperature below which blue-green algae
cells and spores do not survive. The morphometric conditions
are considered to be related to the occurrence of water
blooms and Prescott (1960) generalized that the algal blooms
usually arose in relatively shallow lakes where it is pos-
sible for nitrates and phosphates to be recirculated from
bottom decomposition.

How are bottom deposits related to the algal
blooms? Usually algal blooms occur in lakes with muddy bot-
toms, and rarely in those with a sandy type. I am aware of
no studies to support the idea that the characteristic phy-
sical properties of these two different types of lake bottom
directly influence the occurence of algal blooms. But sev-
eral investigators have reported that the availability of
nutrients in the water is due largely to the recycling and
interchanging from the sediments within a lake (Mortimer
1949). He has given a good review of lake sediments and
their role in lake metabolism. The mud-type sediments are
commonly rich in decomposed organic and inorganic particles
which support a luxuriant phytoplankton when they are
returned to solution. In contrast, the sandy bottom may be
free from accummulation of organic materials and the lake
a poor habitat for algal growth.

The chemical and physical factors of the environ-
ment act not only in controlling the species diversity

of a community of phytoplankton, but sometimes the diversity

of species determines the quantity. The factors which are

favorable for the blue-green algae are high concentrations of

available nitrogen and phosphorus, alkaline water with a pH

higher than 7.0, and an abundance of free CO_2 or half-bound CO_2;

the lake will be of the eutrophic type, and since it is rela-

tively shallow, the water temperature in the summer is high.

Under these favorable environmental conditions, the blue-

green algae are much more successful than other algae because

of their ability to reproduce rapidly and thus they com-

pletely take over the lake. In a lake where any of the above

mentioned environmental factors is lacking, a phytoplankton

community would be established in which other forms dominated

rather than the blue-green algae.

Water blooms of blue-green algae often cause econ-

omic problems due to the unbalanced biological conditions of

the aquatic ecosystems in which they develop. Since they

increase with advancing eutrophication, water blooms have

become serious problems in many impoundments. Hence, with a

view to developing possible control measures, a series of

approaches to the problem have been made. Many highly selec-

tive toxic chemicals have been applied on a short term basis

for controlling excessive algal growth (Palmer 1962).

Palmer (1962) and many other workers recommended copper sul-

fate as the most effective chemical to control the excessive

growth of many species of planktonic algae. It is harmless

to animal life in the treated water at concentrations, such

as 0.2 ppm which is toxic to algae. Unfortunately, in alka-
line water, in which blue-green algal blooms often occur, the
copper sulfate precipitates quickly as copper carbonate or
copper hydrates and in such instances, is considered to be
effective as an algicide only for a short time following its
application. Frequent treatments over a long period of time
to this type of lake result in an accumulation of copper
sulfate precipitate which may cause the bottom fauna to
change (Mackenthun and Cooley, 1952). Fitzgerald (1952)
tested many chemicals and found phygon (2,3-dichloronaphtho-
quinone) was particularly effective for controlling the
bloom-forming blue-greens such as species of *Aphanizomenon*
and *Microcystis*. The increasing bottom organic deposits
derived from the mass of blue-green algal cells killed by
these chemicals may result in an undesirable speeding-up
of eutrophication in the treated waters. It has been sug-
gested that control of blue-green algal blooms on a long
term basis could be achieved by removal of some of the
essential nutrients from the water. Methods for removal
of available phosphorus and nitrogen has been described in
detail by McGauhey et al (1963). For instance, the removal
of phosphate by precipitators such as alum or ferrous sulfate
may reduce the available phosphate up to 96 to 99%. However,
the removal method is mainly applied in sewage treatment and
is found to be costly when applied in lakes. Recently,
Webster (1967) has reported that continuous mixing of the
lake water by means of artificial aeration to prevent

stratification is an ideal method of reversing eutrophication and thus eliminating the occurrence of summer blooms. Theoretically, this method would not be practical in these shallow lakes where thermal stratification and oxygen depletion are uncommon. Dollar et al (1966) proposed the sealing off of the lake, or a significant proportion of it, by sands or poor soil to reduce the availability of recycled nutrients. This approach would seem to be practical in the case of smaller impoundments but appears impractical for larger lakes. At present, there are no satisfactory methods for controlling algal blooms in various kinds of standing water. To develop such control measures constitutes a challenge to future research workers in this field.

METHODS

The course of this study was initiated in the middle of May 1966 and was carried on until early September of 1967. Sampling of phytoplankton and measurements of chemical and physical conditions were done on a weekly basis during the period from May to September in both years. In addition, data were obtained from once-a-month field trips in October, November, and December of 1966 and in March of 1967. The time for each sampling was set between 9:00 a.m. and noon for all stations. Three stations, marked A, B, and C in Figure 4, page 41, were established for quantitative investigation of the phytoplankton and measurements of chemical and physical conditions during 1966. In 1967, in addition to station A, samples were taken from stations D, E, and F, the exact locations of which are indicated in Figure 4, page 41. The reason for changing the sampling sites is that the heterogeneity of phytoplankton, in the sense of regional distribution, is probably greater in marginal water than in the water in the effective length of this lake.

The variation in water level was recorded weekly from a graduated stake which was set in the water in the early summer of 1966. However, the readings on windy days were not very accurate because of waves. The temperature of the surface water was measured by submerging a mercury thermometer horizontally in the water about 2 - 3 cm from the surface. For measuring the temperature of deeper water, the thermometer

was inserted into a rubber-topped 250 ml vacuum bottle. The

water, which was taken from the desired depth by a 2-liter

Kemmerer water sampler, was poured into the thermometer-equip-

ped vacuum bottle and the temperature recorded. This method

may not be entirely satisfactory for water of great depth due

to the change in temperature when bringing the sampler up

through the water column. Water transparency or limit of

visibility, was measured with a Secchi disc of 20 cm diameter.

The details of this method were described by Welch (1948).

The bottom contours were surveyed in the summer of 1966, and

this information was provided by the personnel of Elk Island

National Park. The contour lines appearing in Figure 4,

page 41, do not include those around the islands which were

shown in the original map.

The water chemistry analysis was conducted partly

in the field using the Hach Portable Water Chemistry Kit and

partly in the laboratory by the Provincial Analyst, Univer-

sity of Alberta. The samples for analysis were taken from

the surface water at station A, except for dissolved oxygen

and pH which were tested at different depths regularly. How-

ever, the analysis for bottom water was carried out occasion-

ally and its results were more or less identical with those

from the surface water. Those tests for total dissolved

solids, organic matter, calcium and bicarbonate for which the

Hach Kit was not equipped, were conducted by the Provincial

Analyst in two or four week intervals. Since the Hach Kit

did not measure concentrations of dissolved oxygen over 14 ppm,

the Winkler method was employed during 1967 to overcome this shortcoming. It is worthwhile to mention that during the periods of waterbloom the water samples were filtered through filter paper before undergoing the chemical tests, except for the test for dissolved oxygen.

The procedures for testing these chemical substances are described in detail by the manual supplied by the Hach Chemical Company. I felt that this equipment provided a reasonably satisfactory set of data when checked with those obtained from the Provincial Analyst, except for nitrate nitrogen, which was analyzed by the Provincial Analyst. Most methods used in the Hach Chemical Analysis Kit were developed from Standard Methods (1965) using the colorimeter photo cell. Alkalinity was determined from the phenolphthalein standard titration. Hydrogen ion and silica were determined from colorimetric methods. Ortho-phosphate phosphorus was developed from the stannous chloride method. The measurement of dissolved oxygen is from the modified Winkler colorimetric method.

Samples of sediments were obtained by towing the Kemmerer sampler along the bottom for a short distance and closing the cylinder prior to bringing it up. A layer of surface deposits was collected by this method. Samples obtained by this method from station A in July of 1966 were air dried and used for chemical analysis. In July of 1967 the samples for chemical testing were obtained with a 6-inch square Ekman dredge at those stations where the water samples

were taken. These fresh wet sediments were poured into poly-
ethelene bags and transported to the testing laboratory. The
tests for nitrogen, phosphorus, potassium, sulfate, free lime,
pH and conductivity were conducted by the Agricultural Soil
and Feed Testing Laboratory, University of Alberta, Edmonton.

Biweekly collections of bottom sediments were taken
from each sampling station. A small portion of each sample
was diluted with distilled water, mounted, and examined under
the microscope for epipelic algae. In addition to the study
of bottom deposits, epipelic algae were collected by means of
glass slides used as artificial substrates. These slides
were racked in slide boxes and then placed along the lake
shore. A weekly replacement of these slides was made. The
replaced slides were immediately racked in Coplin staining
jars which were filled with distilled water. Qualitative
examinations of the attached algae were made upon returning
to the laboratory. Large numbers of slides were examined
after being preserved in the refrigerator when the examina-
tion could not be finished within three hours after collec-
tion.

The epiphytic algae were removed from the stems of
macroscopic vegetation such as *Scirpus*, *Phragmites* and *Typha*
by means of a scalpel and studied in the fresh condition to
provide information on the species present.

During the study period a survey of the aquatic
macrophytes of Astotin Lake was carried out. Floating and
emergent species were collected by hand. Submerged plants

were collected with a grapple hook. A binocular stereoscope was used for identifying these plants. Aquatic fauna was collected casually during the study period. A dip net was employed for catching the macroscopic fauna such as snails and *Gammarus*. The planktonic animals such as *Daphnia* were collected with a size 25 Wisconsin net.

Water samples for phytoplankton analyses were taken with a Kemmerer water sampler with a capacity of 2 liters. In hopes of obtaining a more accurate estimate of the average organism abundance throughout the water column, the water samples at each station were made up by taking equal amounts of water from surface, middle and bottom layers and mixing them together to make a total sample of 2 liters. The taking of samples at one meter intervals throughout the water column was carried out at station A during 1967. The water samples were poured into 2 liter polyethelene bottles for transporting to the laboratory. These bottles were placed in a cooling chest and covered with a raincoat to keep out the sunlight. In the laboratory, 1 liter of each water sample was withdrawn subsequent to vigorous agitation of the polyethelene bottle. This 1 liter of well-mixed water sample was immediately concentrated using a Foerst continuous-flow centrifuge (approximately 20,000 rpm) at the rate of 1 liter each 6 minutes according to the instruction of Foerst Mechanical Specialties Company, Chicago. The algal concentrate which adhered to the inside bowl of the centrifuge was wiped off with a paraffin-tipped glass rod and rinsed with distilled

water until the total volume was made up to 20 ml. This con-
centrate was then poured into a screw-topped vial which was
stored in a refrigerator (4°C) until analyzed. As a rule,
all samples were concentrated within three hours after col-
lection in the field. To provide additional information
about the variety of net plankton in the water between the
stations a biweekly collection with a size 25 Wisconsin plank-
ton net was carried out. However, the plankton net samples
showed that the species of net plankton were almost identical
to those collected with the Kemmerer sampler. The one excep-
tion was a *Ceratium* species which occurred in extremely small
numbers in the net collection and was absent from Kemmerer
samples during 1967. Very low efficiency of collection with
the plankton net occurred during the waterblooms because the
net meshes were largely clogged by the algal mass.

The centrifuge method was found to be the most
satisfactory means in terms of speed and efficiency for con-
centrating even the nannoplankton, when compared to other
methods such as the plankton net or sedimentation. Possible
errors in estimates arising from the loss of those algae with
great buoyancy were assumed negligible since frequent re-
centrifugations revealed that the loss of such groups of
algae from initial centrifuging was minimal. These extra
buoyant forms were mainly certain blue-green algae such as
Microcystis aeruginosa, Aphanizomenon flos-aquae and
Anabaena species. An unavoidable disadvantage of centrifug-
ing was the fragmentation of some colonial forms. Large

numbers of single cells were separated from the colonies of
Anabaena species and *Microcystis aeruginosa*. These single
cells often appeared identical with natural unicellular forms.
For instance, the groups of separated *Microcystis aeruginosa*
cells were like the colonies of *Chroococcus* under low magni-
fication. In order to overcome this disadvantage, 1 liter
of each sample was concentrated to 50 ml with filter paper.
This filter method was employed to obtain the concentrate for
estimating the colonies of *Anabaena*, *Microcystis* and
Aphanizomenon species during their bloom period. However, the
relatively large pores of the filter paper caused the loss
of a small number of these blue-green algal cells. Following
centrifuging, the raw concentrate was thoroughly mixed by
vigorous agitation in the vial. Two drops of the mixed con-
centrate were withdrawn with an eye dropper and dropped on
to glass slides for examination of the species composition
under the compound microscope.

Throughout the study all collected planktonic algae
were identified to species if possible. Most species were
determined under 100X or 400X magnification except for a few
species of nannoplankton which were examined with the oil
immersion lens (1,000X magnification). Subsequent to iden-
tification and recording of the species and prior to quanti-
tative analysis, the remaining concentrate was preserved in
5% formalin. This treatment with formalin was not only for
the purpose of fixation of the algal cells, but in order to
prevent their autolysis and decomposition. I should point

out that the quantitative analyses for all samples often took several days, and, some organisms in a preserved concentrate showed slight contraction and distortion of body form.

The enumeration of phytoplankton was made at a magnification of 100X (10X ocular and 16 mm objective). Standard Methods (1965) recommended that the medium power (8 mm objective) with a working distance of approximately 1.6 mm can be used with a standard counting cell 1 mm deep. Twice the magnification of the low power objective is convenient in the examination of small organisms during the process of counting. However, this advice was not employed in my numerical method because of the lack of an 8 mm objective. A Whipple ocular micrometer was employed to delimit the microscopic field within the Sedgwick-Rafter counting cell. One milliliter of preserved concentrate was pipetted out of a well shaken vial and introduced into a 20 ml graduate cylinder. Dilution with distilled water was accompanied by agitation until the desired concentration was reached. Immediately following mixing, a 1 ml portion was withdrawn by means of a wide-mouth pipette and transferred into the 1 ml Sedgwick-Rafter counting cell. A cover slip lying diagonally across the cell was permitted to move into place on the counting cell. After a 5 minute settling period the sample was ready for the enumeration procedure. Two cell mounts and ten random fields per mount were made for each sample. The count for each species was based upon the number of cells except for *Aphanizomenon* and *Microcystis*, which were counted

by numbers of colonies of occupied fields. The variation in thickness of these colonies was beyond reasonable estimate and therefore, no attempt was made to provide the actual cell numbers.

The results of the numerical counts for each species were recorded as the number of cells per milliliter. Multiplication of the results of the micrometer field count by a factor gives the approximate actual number of each organism in 1 ml water. The factor is calculated by the following formula.

$$\text{factor} = \frac{a}{b} \times \frac{c}{d}$$

where,

a = number of fields in 1 ml counting cell 1 mm deep;

b = number of fields counted

c = ml concentrate

d = ml original sample

Biweekly collection of the top layers of the sediments and bottom layers of water were taken from those stations where water samples were obtained. The mixtures of water-mud samples were stored in plastic bags and placed in refrigerator at the freezing point for two weeks and -15°C for a month before culture was initiated. After defrosting at room temperature approximately 1 cm^3 of each water-mud sample was transferred into a flask and diluted with 50 ml of distilled water. Vigorous shaking for a few minutes was followed by passing the dilutant through a fine filter paper.

This filtered, slightly turbid material was concentrated to 5 ml with a Foerst centrifuge. Microscopic examination revealed a great number of particles which included algal cells, soil and debris. However, I could not determine with confidence the variety of reproductive structures (akinetes, heterocysts or other resting spores) which belong to the phytoplankton.

Modified Chu number 10 nutrient solution (Gerloff 1950) was used to prepare liquid and solid culture media. One ml of each water-mud concentrate was inoculated into the liquid medium and 1 ml on the agar plate. All cultures were placed in a growth chamber with an illumination of a 16 hour light period and 8 hour dark period. The illumination was provided by a series of cool-white fluorescent tubes, with an intensity of 60 ft-c at the culture level. Examination for initiation and development of algal cells was carried out every three days after inoculation.

DESCRIPTION OF STUDY AREA

I   General Location

Astotin Lake is located in the north end of Elk
Island National Park which is situated in the Beaver Hills of
Central Alberta. The lake center lies at a point of longi-
tude 112°51' West and latitude 53°41' North. The city of
Edmonton is twenty-five miles west of the lake. The relative
positions of Elk Island Park and Edmonton are shown in
Figure 1, page 32.

II   Geological Features

There are no known outcroppings of the Cretaceous
bedrock in the study area. The knob and kettle topography is
a result of a glacial formation known as hummocky-dead-ice
moraine and the mantle of glacial drift is up to about one
hundred feet thick in the study area. The Wisconsin glacia-
tion left a rough terrain with characteristic surface deposits
of till, outwash sand, and superficial and impounded glacial
lake sediments (Bayrock and Hughes 1962).

In Astotin Lake the sediments, a layer immediately
above the moraine, are mainly deposits of silt, muck, sand
and marl. Parts of the southern shores of Archer Island, the
north-west shore off High Island and the artificial beach area
are sandy.

III   Topography and Soils

The gently undulating lake bottom and the surround-
ing area reflect typical hummocky dead-ice moraine topography.

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Figure 1. Location of Astotin Lake in Relation to the City of Edmonton
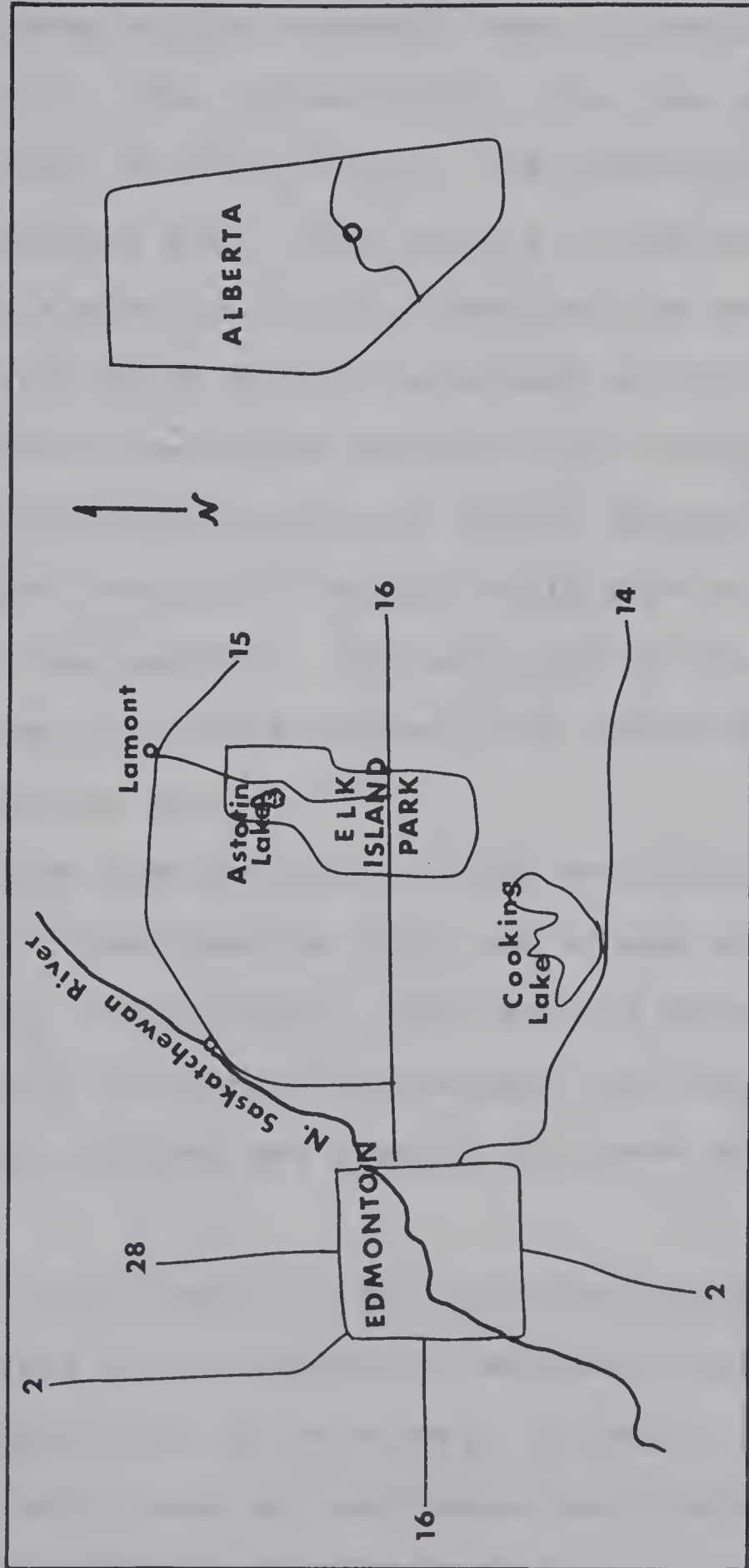
Rolling areas surround Astotin Lake along the south, east and northeast sides. Notably, some higher hills or 'knobs' are located on the southwest and far east sides of the lake. The general topography of the catchment area is demonstrated by Figure 2, page 34. The islands within the lake are of similar glacial origin as these hills. The remainder of the topography is relatively flat. The terrain to the west and northwest gradually slopes down to the level of the North Saskatchewan River into which Astotin Lake used to drain.

Orthic grey-wooded podzolic soil covers most of Astotin Lake's surrounding area in which, however, some small bogs and sloughs containing organic soils made up of sedge and moss peats are located. The soil type of this area indicates that these hills were covered with coniferous forest about ten centuries ago.
This Cooking Lake Loam soil is a fairly well drained orthic grey-wooded soil developed on till, and stones occur throughout the profile. Structurally, this soil is solonetzic, in which the content of calcium, magnesium, and sodium is usually stable and these cations are present in almost equal amounts.

IV Climate
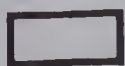
The meterological data summarized in Table 1, page 35, were obtained from the Edmonton meterological station of the Dominion Department of Transport. Climatic information describes the study area as continental and characterized by relatively warm summers and cold winters.

The mean temperatures, May to September inclusive,

Figure 2. The Topography of Watershed of Astotin Lake

TABLE 1

Meteorological Summary for the Period from January 1966 to December 1967
with Long-Term Averages (Department of Transportation at Edmonton)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean Temperature (°F)												
1966	-8.3	13.4	24.5	33.7	54.3	56.8	62.9	59.7	56.3	41.0	15.5	14.1
1967	4.6	15.5	14.7	31.7	51.0	57.7	64.1	66.2	60.8	42.2	28.4	14.3
Normal	6.6	11.2	22.1	39.5	52.1	57.8	63.1	60.0	51.5	41.2	24.5	13.3
Precipitation (inches)												
1966	1.39	0.50	0.20	0.73	1.11	0.89	2.45	6.44	0.34	0.28	0.66	0.47
1967	1.03	0.78	1.22	0.53	1.58	1.72	2.02	2.93	0.03	1.61	0.91	1.02
Normal	0.95	0.77	0.83	1.10	1.83	3.15	3.34	2.55	1.35	0.90	0.88	0.99
Sunlight (hours)												
1966	67.6	119.9	178.6	217.5	320.5	293	308.4	231	203.2	131.6	79.9	83.6
1967	90.7	116.6	129.7	229.6	273.7	282.4	310.2	344	247.6	143.6	127.5	66.9
Normal	85.6	114.2	167.6	221.7	267.2	255.1	309.3	269	187.3	159.4	100.8	78.2
Wind (mph)												
1966	8.3 (SE)	7.5 (S)	8.6 (S)	10.7 (N)	11.7 (NW)	9.0 (SW)	8.8 (NW)	9.0 (NW)	8.3 (S)	9.7 (NW)	9.5 (S)	7.1 (S)
1967	8.3 (S)	8.6 (S)	9.2 (NE)	9.6 (S)	9.8 (NW)	9.7 (NW)	9.5 (NW)	9.0 (S)	9.7 (S)	10.0 (SNW)	9.4 (SW)	9.6 (N)
Normal	7.6 (S)	8.6 (S)	8.9 (S)	10.4 (S)	10.5 (NW)	9.8 (NW)	8.8 (NW)	8.3 (NW)	9.0 (NW)	8.8 (S)	8.2 (S)	7.7 (S)

were 58°F and 59.3°F during 1966 and 1967 respectively. Both

of them were higher than the long term average, 56.9°F. The

warmest month of 1966 was July with a mean temperature of

62.9°F and of 1967 was August, with a mean temperature of

66.2°F. January was the coldest month in both 1966 and 1967.

The mean temperature of late summer, August and September

inclusive, of 1967 was about 6°F (63.7 - 58.0°F) higher than

that of 1966.

The total annual precipitation during the first

nine months of 1966 was 15.45 inches while the precipitation

during the first nine months of 1967 was 11.84 inches.

Approximately 70% of the total yearly precipitation was in

summer rain and the rest was in snow. During 1966 the rain-

fall of 11.19 inches was 2.19 inches more than that of 1967.

The temperature-precipitation climatograph of the

study area, based on twelve months' data, is shown in Figure 3,

page 37. This polygon shows a climatic comparison between

1966 and 1967.

Generally, the prevailing winds in the study area

are from the south during the winter and from the northwest

during the summer. Wind velocity averaged about nine miles

per hour with little variation throughout the year. But

strong winds, over fifteen miles per hour did occur during

the summer period.

Long daylength with bright sunshine during the

summer characterizes this temperate region. A significant

difference of total sunlight hours during the summer period,

Figure 3. Climatographs Showing Mean Monthly Temperature
and Total Monthly Precipitation for Edmonton Area, 1966 and 1967
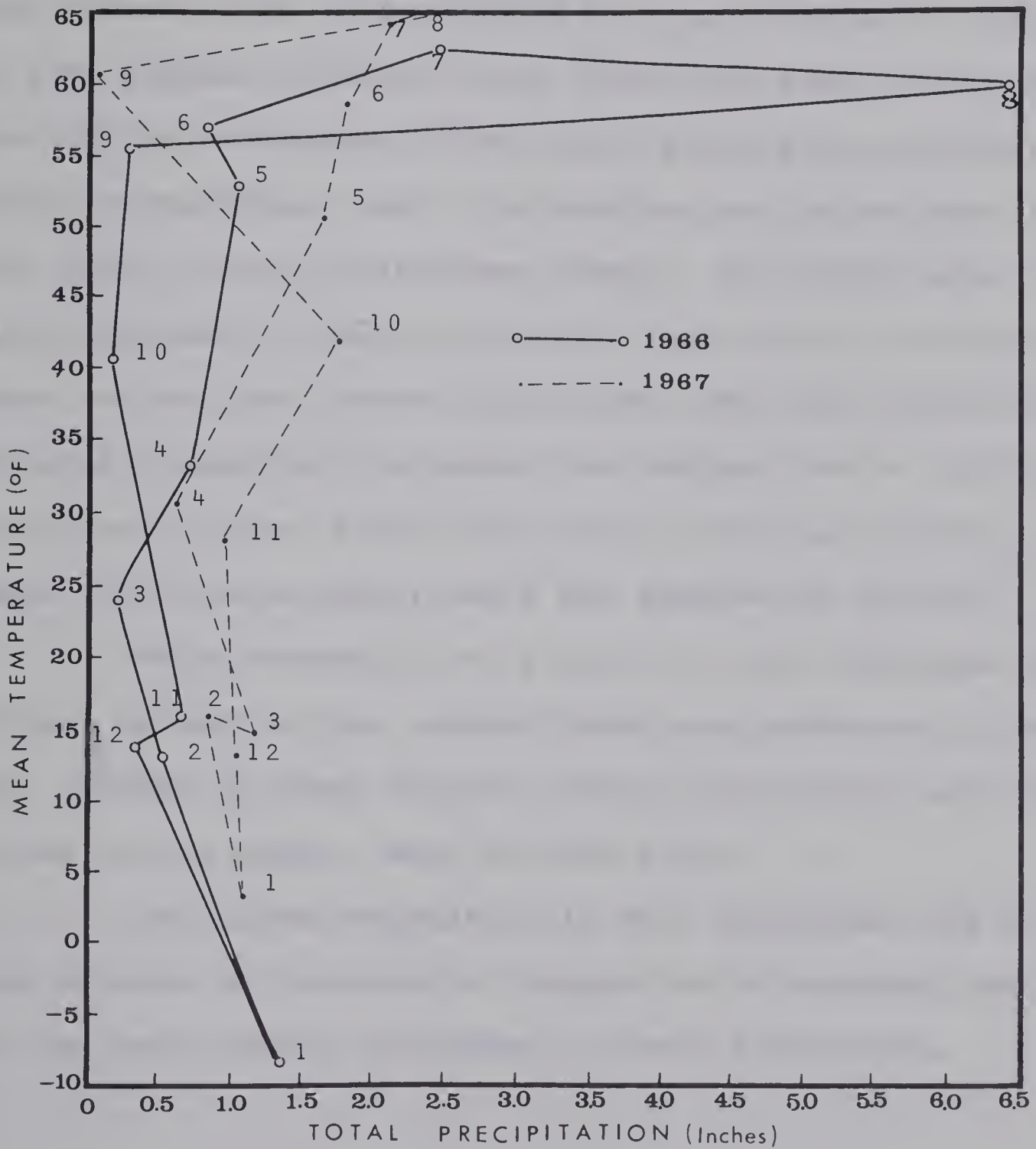
June to September, was found between 1966 and 1967. The for-mer had 935 hours and the latter had 1,183 hours.

V Terrestrial Vegetation

Lake Astotin is located on a highland of somewhat mixed forest which is surrounded by Aspen Parkland. There are some pockets of boreal type forest and some grassy open-ings similar to meadows. The poplar association consists of *Populus tremuloides*, and *P. balsamifera* as the dominant trees which form a nearly continuous canopy. The shrub layer is mainly composed of *Corylus cornuta, Amelanchier alnifolia, Cornus stolonifera, Prunus virginiana*, and *Rosa acicularis*. The herbs blanketing the ground are *Galium boreale, Epilo-bium angustifolium, Aster ciliolatus, Pyrola asarifolia*, mosses (*Hylocomium* spp.) and a few species of grasses.

White spruce (*Picea glauca*) is well developed and dominant on most of the islands which are scattered in the lake. Clumps of paper birches (*Betula papyrifera*) are found on some of the higher, well drained soils.

The climax vegetation is well developed only on these islands but terrestrial vegetation surrounding the lake has been greatly disturbed by human activities.

FEATURES OF ASTOTIN LAKE

I Physical Features

  1. Morphometry

      The detailed morphometric parameters are listed in
Table 2, page 40, and the bathymetric contour map is given in
Figure 4, page 41. In general, Astotin Lake is triangle
shaped, and oriented at a line running from NNW to SSE. The
area with maximum depth of seven meters is located between
High Island and Archer Island and forms a somewhat deeper
water channel across the single basin within the lake. This
is the main limnetic trophogenic zone found in Astotin Lake.
A considerable area of relatively shallow water extends along
the northwest and west sides of the lake. Possibly it has
resulted from wave sweep.

      Some European limnologists claimed that the mean
depth is the factor which determines whether a lake is eutro-
phic or oligotrophic. They have also said that in oligo-
trophic lakes the volume of hypolimnion is greater than that
of epilimnion, and that in eutrophic lakes the reverse occurs.
The mean depth of Astotin Lake is only 3.04 meters and this
shallowness allows the whole water body to be productive.
There is no doubt that Astotin Lake can be classified as an
eutrophic type.

      From long term sedimentation the lake basin has
developed a gentle slope and a rather flat bottom. According
to the echo sounding records of 1966 the bottom deposit was

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TABLE 2

Morphometric Parameters

Area	5.616 km^2
Volume	$15.109 \times 10^6 \text{m}^3$
Maximum length	4.25 km
Maximum effective length	4.00 km
Maximum width	2.88 km
Maximum effective width	2.75 km
Mean width	1.09 km
Maximum depth	7.01 m
Mean depth	3.04 m
$\dfrac{\text{Mean depth}}{\text{Maximum depth}}$	0.43
Shoreline length	19.5 km
Shore development	2.3
Volume development	1.29
Direction of major axis	NNW - SSE
Elevation	712.2 m

Figure 4 . Contour Map of Astotin Lake Showing
Sampling Stations

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ASTOTIN LAKE

Legend

● Sampling station
O Water level stake

4′ contour interval

RASPBERRY
I.

HIGH
I.

LONG
I.

ARCHER
I.

CRANE
I.

ELK
I.

1 MILE
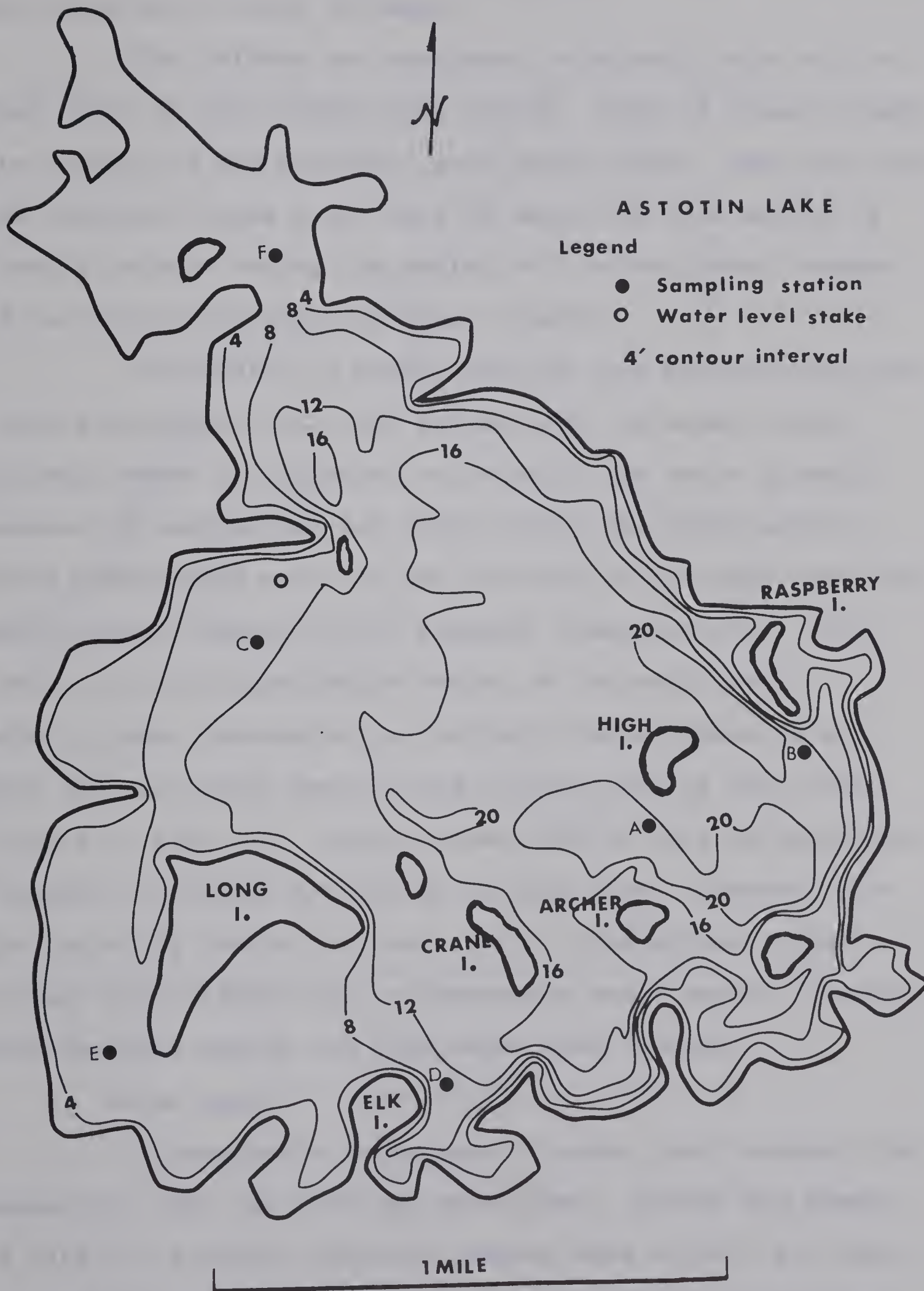
about 20 to 25 feet around the High Island channel area where
the water was 20 feet in depth.

Ten islands are scattered in Astotin Lake, all of
them small in area except Long Island. Most of these islands
are located in the southeast part of the lake. Here the sinu-
ous shoreline forms a few bays in which the wind action is
greatly reduced during the period of ice-free water because
of the protection given by these islands.

Lake water is mainly derived from precipitation and
surface drainage during the spring thaw and summer rains.
Although water infiltration arriving in the basin through
seepage or springs was not found during the study period,
ample underground water in the vicinity of the park area has
been located (Bayrock 1967, personal communication). The
path of the drainage, which begins at the north end of
Astotin Lake, terminates in the North Saskatchewan River.
This may be clearly seen in the official map of this area
(Figure 5, page 43). Martin Creek used to have an important
function in keeping Astotin as an open lake. However, dur-
ing the study period, it was a small, intermittent creek
through which flowed only an extremely small amount of water
from the lake during the high water level period.

2. Water Level

A remarkable difference of water level between the
summers of 1966 and 1967 can be noticed. During the summer
of 1966 the rainfall was much greater than in 1967 and this
resulted in the higher water level. During the late summer

Figure 5. The Path of Martin Creek and Location of
Dam in Relation to Astotin Lake

10 Miles
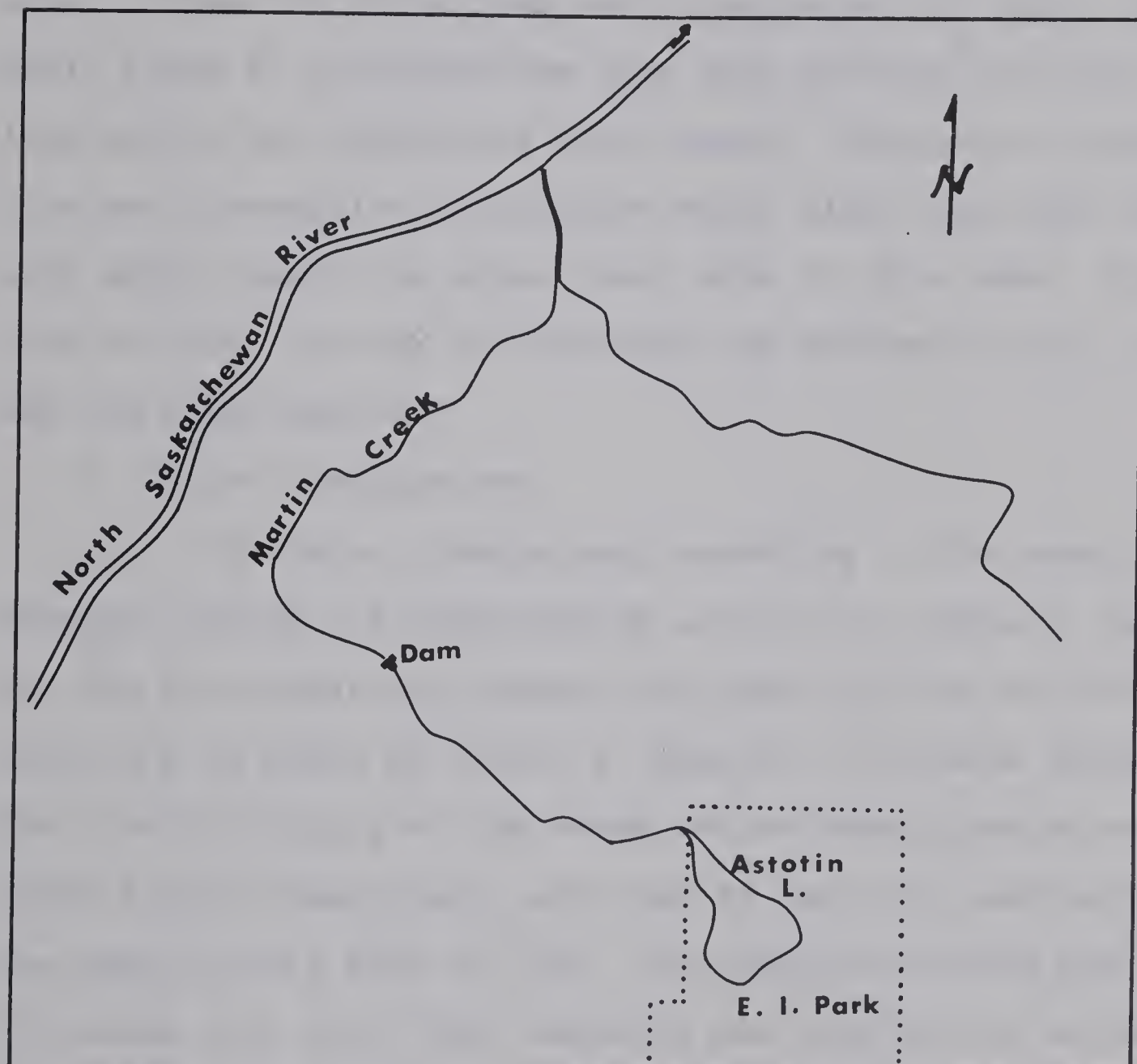
and fall of 1966 the large amount of rainfall maintained the
relatively high water level. The rainfall of 1967 was much
less than in the previous year, especially during the period
of July to September, and the water level dropped consider-
ably, a total of 23 cm from May to September of 1967. Some
small parts of the shoreline area were extended into the
lake due to the decreasing water depth. Generally, evapora-
tion and consumption through the water plant were main fac-
tors which caused the water level drop in this lake. The
loss of water through the drainage was extremely minor dur-
ing the study period.

3. Water Transparency

The water transparency according to the Secchi disk
readings during the study period is given in Table 3, page
45, and the comparison between the years of 1966 and 1967 at
station A is shown by Figure 6, page 46. The data indicate
that the visibility of the water was extremely low at most
times during these years, and that it was much less during
the year of 1967 than in 1966. The maximum reading was
315 cm on July 8 of 1966, while it was only 148 cm on June 5
of 1967. The minimum was 48 cm on July 12 of 1966 and 23 cm
on August 27 of 1967.

In general, the seasonal pattern of water trans-
parency showed that an increase in transparency occurred in
the spring due to a decrease in turbidity after the spring
turnover. During the spring turnover considerable quantities
of diatoms accompanied by nonliving particles affected the

TABLE 3

Secchi Disk Water Transparency (cm) at Station A, B and C

for 1966 and at Station A for 1967

1966

	June					July				August				Sept.	
	1	8	15	21	28	5	12	19	26	3	10	16	23	6	13
Station A	200	315	200	200	257	130	48	102	125	63	92	82	83	78	66
Station B	-	300	120	120	278	145	74	89	153	138	90	90	95	70	63
Station C	-	280	250	250	228	187	130	95	135	92	82	-	90	90	68

1967

	June				July					August				Sept.	
	5	12	19	26	4	10	17	24	31	8	15	21	27	5	
Station A	148	100	95	39.5	40	40	40	55	60	65	73	65	23	48	-

Figure 6. Comparison of Seasonal Variation in Secchi Disk Water Transparency at Station A for the Period from Spring to Autumn between 1966 and 1967

47
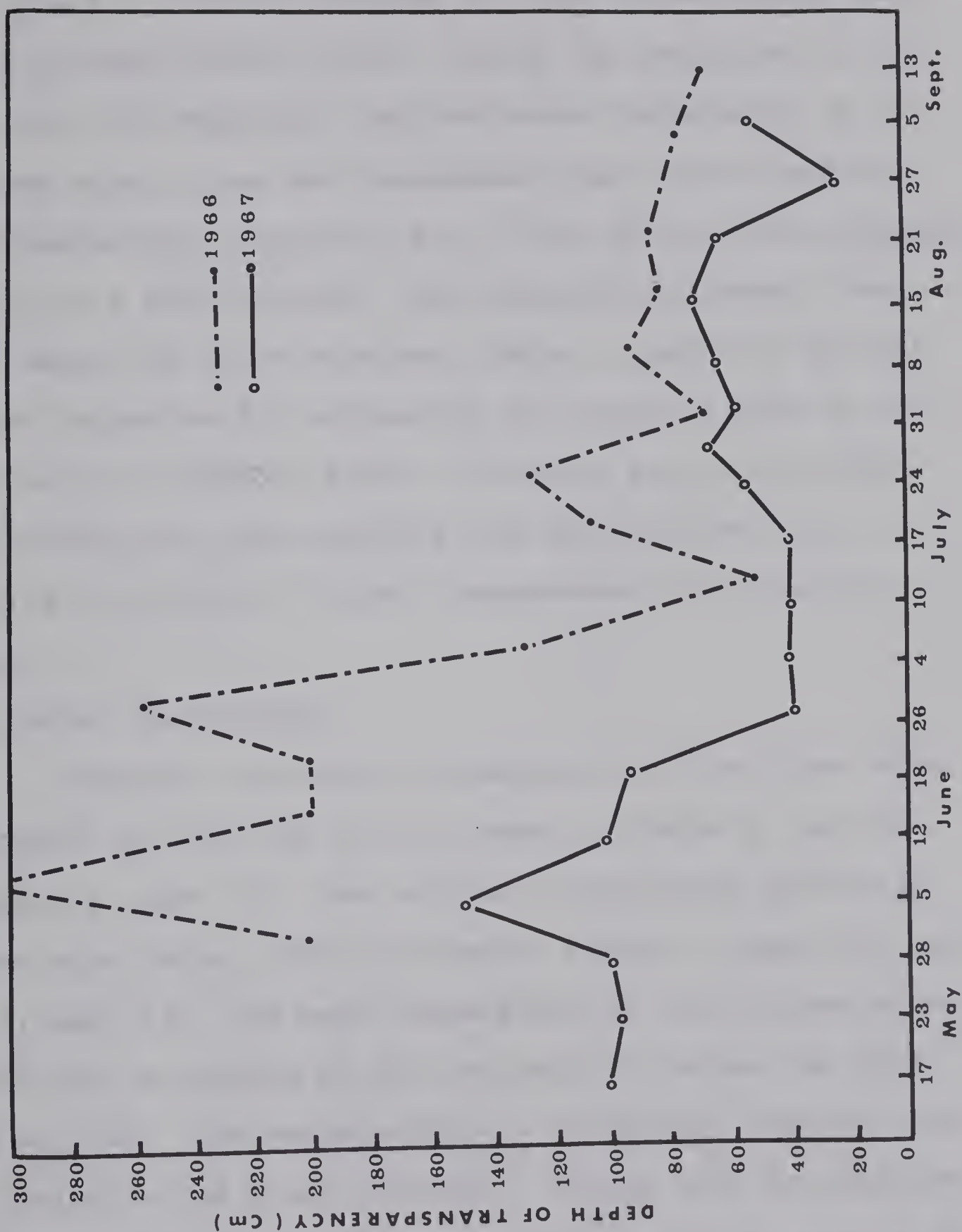
tubidity and color of the water. From early June to mid-July
of both years the great decrease of water transparency was
due to the summer water bloom. During the remainder of the
season until mid-September the continuous occurrence of a
blue-green algal bloom and decomposed algal cells kept the
water transparency constantly low. Wind action also affected
turbidity to a great extent. The variation of water trans-
parency among the three stations (Table 3, page 45) may not
be a good criterion for evaluating the standing crop of phy-
toplankton on a seasonal basis. The wind action and other
weather conditions were possibly the main factors which
caused the variations of water transparency from station to
station.

    4. Water Temperature

        Seasonal variation in temperature of surface water
at station A in 1966 and 1967 is shown in Table 4, page 48,
and Figure 8, page 53. The vertical temperature profile at
the same site during 1967 is given by Figure 7, page 49, and
Table 4, page 48. The mean temperature of the surface water
was 19°C with a maximum of 24°C on July 12 during the study
period of 1966. The temperature was relatively lower during
August owing to the great rainfall. During 1967 the maximum
temperature of the surface water was 23°C with an average of
18°C. When the study began, the water temperature profile
indicated that the water was in a condition of homothermy,
in which the temperature is fairly even throughout the water
column. Evidence of thermal stratification was noticed on

TABLE 4

Water Temperature (°C) for the Period

May 18, 1966 to November 18, 1967

DATE		Surface	1 M	2 M	3 M	4 M	5 M	6 M
1966								
May	18	11.0			11.0			11.0
June	1	13.2			--			--
	15	16.1			--			--
	28	19.7			19.2			17.8
July	12	24.0			20.8			20.2
	26	18.0			17.9			17.5
August	10	18.6			18.8			18.6
	23	19.2			17.0			16.2
September	13	16.4			16.0			15.8
October	3	11.0			11.0			11.0
December	20	0.5			1.0			3.2
1967								
March	3	--	--	--	2.5	--	--	4.0
May	17	4.5	4.5	4.5	4.5	4.5	4.5	4.5
	23	13.2	13.0	12.0	11.8	11.0	9.8	9.2
	28	14.5	14.5	14.2	14.2	14.2	14.0	14.0
June	5	15.8	15.8	15.5	15.5	15.1	15.0	15.0
	12	14.5	14.0	14.0	14.0	13.8	13.8	13.6
	26	21.4	20.4	(19.5	16.5)	16.3	16.0	15.5
July	10	17.2	17.2	17.2	17.2	17.1	17.1	17.1
	24	21.3	22.2	21.1	21.2	21.0	21.8	--
	31	21.0	20.8	20.6	20.5	20.5	20.5	20.2
August	8	19.5	19.2	19.0	18.7	18.5	18.3	18.2
	15	23.0	23.0	23.0	23.0	(22.8	21.0)	20.2
	21	22.0	21.8	21.3	21.1	20.5	19.0	19.5
	27	20.0	19.8	19.1	19.0	18.5	18.2	18.2
September	5	20.0	19.1	18.5	18.5	18.3	18.3	18.1
November	18	3.0	3.2	4.0	4.1	4.1	4.2	4.2

Figure 7. Vertical Distribution of Water Temperature for the Period
March 5 to November 18 of 1967 at Station A
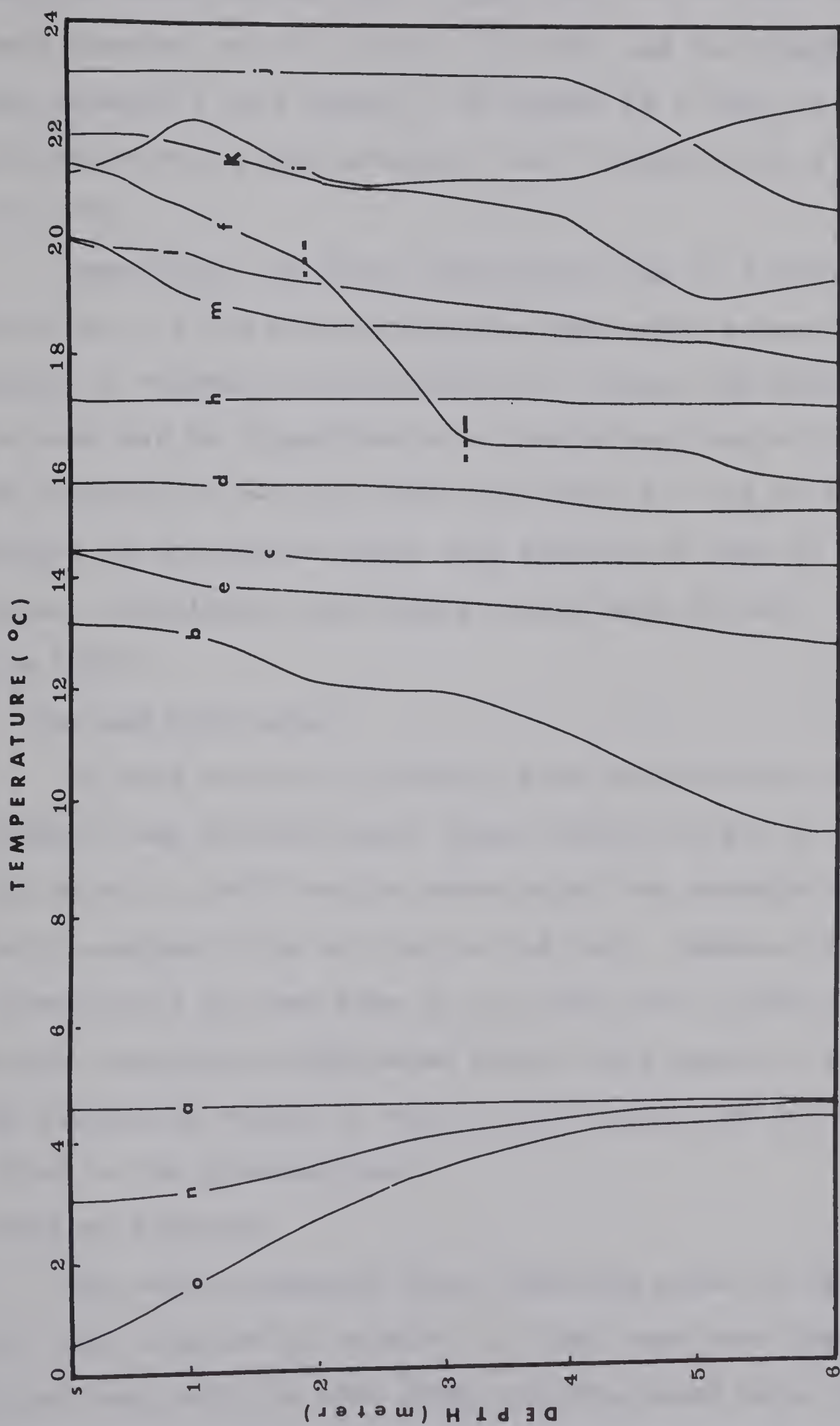
(a) May 17; (b) May 23; (c) May 28; (d) June 5; (e) June 12; (f) June 26; (h) July 10;
(i) July 24; (j) August 15; (k) August 21; (l) August 27; (m) September 5;
(n) November 18; (o) March 5

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two sampling dates during 1967. The first was on June 26 with
a thermal gradient of 3°C, (19.5 - 16.5°C) and the thermocline
occurred between 2 to 3 meters. On August 15 a sort of micro-
stratification took place between 4 and 5 meters with a grad-
ient of 1.8°C.

Generally, the water temperature was in a holomictic
condition most of the time during the open water seasons. The
occurrence of thermal stratification was casual and momentary.
Astotin Lake may be classified as a "temperate lake with the
surface temperature varying above and below 4°C and with the
temperature of the bottom water very similar to that of sur-
face water, circulation continuous except when frozen"
(Whipple 1952).

5. Ice and Snow Cover

In 1966 the ice in Astotin Lake thawed during the
first week of May and the water froze toward the end of Novem-
ber. On March 3, 1967 the ice cover depth was recorded as
98 cm with another 25 cm of snow on the top. Because of this
thick coverage of ice and snow it is likely that light pene-
tration was completely eliminated during this period. The
ice was completely melted by May 18, 1967 which was two weeks
later than in the previous year.

II Chemical Features

The water chemistry data, which are given in Table 5,
page 51, were obtained at station A. Some important chemical
properties dealt with in this study are discussed below and
their variation in concentration throughout the study period

Table 5.   Chemical Data of Surface Water from Station A

for the Study Period of 1966 and 1967

1967	March		May			June									July									August							Sept.		Oct.	Nov.	Dec.
	3	17	18	23	28	1	5	7	12	14	19	21	26	28	4	5	10	12	17	19	24	26	31	3	8	10	15	16	23	28	5	14	4	9	20
Alkalinity (Phenol)	--	--	--	--	40.0	25.0	25.0	20.0	25.0	20.0	25.0	25.0	50.0	20.0	50.0	25.0	40.0	60.0	50.0	--	30.0	32.0	15.0	30.0	20.0	35.0	30.0	30.0	40.0	--	30.0	--	--	--	--
Alkalinity (Total)	250.0	190.0	--	180.0	180.0	185.0	180.0	170.0	185.0	180.0	175.0	180.0	160.0	170.0	150.0	180.0	155.0	180.0	155.0	--	160.0	180.0	183.0	160.0	160.0	170.0	160.0	180.0	190.0	165.0	175.0	--	180.0	200.0	--
*Bicarbonate	268.4	--	--	--	--	--	--	70.8	164.7	--	--	183.0	--	--	189.1	--	--	36.6	189.1	--	--	--	183.0	122.0	--	--	183.0	134.2	--	103.7	--	103.2	140.3	--	--
*Calcium	52.0	29.0	36.0	--	--	40.0	--	36.8	--	--	--	38.0	--	--	24.8	--	--	27.6	21.6	--	--	--	22.4	37.4	--	--	25.6	2.5	--	24.0	--	43.2	34.0	--	44.1
Copper	--	0.26	--	--	--	nil	0.2	nil	0.1	nil	0.1	nil	0.1	nil	0.15	0.15	0.03	--	0.07	--	0.02	nil	0.12	nil	0.2	nil	0.1	nil	nil	--	nil	--	--	0.09	--
Hardness	243.0	150.0	--	--	160.0	175.0	170.0	60.0	170.0	160.0	160.0	160.0	115.0	155.0	125.0	160.0	160.0	170.0	135.0	--	130.0	176.0	185.0	170.0	160.0	170.0	125.0	160.0	165.0	140.0	135.0	--	175.0	180.0	215.0
*Manganese	--	nil	--	--	nil	nil	0.5	nil	0.25	nil	0.4	nil	--	nil	0.5	--	0.25	--	0.3	0.25	--	--	0.25	nil	0.02	--	0.7	nil	nil	0.7	--	102.0	0.9	0.2	--
*Organic Matter	57.0	78.8	--	--	--	--	--	21.0	84.0	--	--	280.0	--	--	280.0	--	--	204.0	80.0	178.0	--	--	71.0	276.0	--	--	103.0	169.0	--	121.0	--	102.0	80.0	--	--
*Total Dissolved Solids	492.0	260.0	232.0	--	--	140.0	--	226.0	400.0	--	--	280.0	--	--	280.0	--	--	204.0	262.0	178.0	--	--	270.0	376.0	--	--	292.0	169.0	372.0	--	--	334.0	264.0	--	--
Hydrogen ion	--	--	8.0	8.9	9.4	8.4	--	8.4	9.2	8.5	8.9	8.7	9.9	9.6	9.8	--	10.0	9.1	9.7	--	9.2	9.3	9.0	9.4	8.8	8.9	9.0	9.3	9.5	9.5	9.7	9.4	9.2	9.0	8.8
Silica	--	0.85	2.6	nil	0.08	7.0	--	2.5	0.1	11.5	0.15	--	0.15	--	0.7	nil	2.8	--	3.5	--	3.0	13.5	--	15.0	6.5	15.0	5.1	--	13.5	8.5	5.0	--	0.75	0.25	1.0
*Iron	0.12	0.15	nil	nil	0.05	nil	nil	1.0	nil	--	nil	--	0.03	nil	nil	nil	nil	--	nil	0.25	0.2	--	nil	nil	0.03	--	nil	--	nil	nil	nil	--	0.1	0.04	0.1
Dissolved Oxygen	2.7	14**	--	14**	--	10.0	9.2	9.5	9.0	9.6	12.5	10.5	16.4	11.0	14.6	13.3	10.6	14.0	7.4	14.0*	1.2	6.0	6.0	11.0	5.0	6.5	9.2	6.5	13.5	12.0	13.0	8.5	--	--	8.7
*Nitrate Nitrogen	--	nil	nil	nil	--	nil	nil	nil	nil	nil	nil	nil	--	nil	nil	nil	nil	--	nil	nil	--	--	nil	nil	nil	--	nil	nil	nil	nil	nil	nil	nil	nil	--
Ortho-Phosphate	0.3	--	0.2	--	--	1.0/0.4	0.19	0.4	0.4	1.1	0.35	1.1	0.02	1.2	0.02	1.1	0.02	1.0	0.25	1.1	1.2	1.0	0.6	nil	1.1/0.8	0.6	0.6	nil	0.9	1.0	0.6/0.65	nil	0.3	0.4	0.4

is illustrated by Figure 8, page 53.

1. Dissolved Oxygen

A. Oxygen Content of the Surface Water (Figure 8, page 53)

In 1966, during the period of vernal circulation, the surface water contained about 9.5 to 11 ppm of oxygen roughly corresponding to 95 to 100 per cent saturation. The condition of oxygen supersaturation occurred frequently during the summer with a maximum value of over 170% on July 19. No noticeable oxygen deficit in the surface water was recorded during the study period of 1966.

On March 3 of 1967, almost three months after the surface water was completely frozen, the oxygen concentration in the surface of the water beneath the ice was 2.7 ppm corresponding to 18% saturation. Presumably, this low oxygen content under the ice-snow cover was due to biochemical oxidation. The concentration of oxygen in the whole water body was over 14 ppm corresponding to a value greater than 140% saturation during the period of vernal circulation of 1967. Such supersaturation corresponded with the spring bloom of diatoms. The condition of supersaturation in the surface water also occurred during the periods June to July 4, and August 15 to September 5. The maximum and minimum values were found to be 160% and 13% saturation on July 4 and 24 respectively. The oxygen deficit on July 24 was due to the decomposition of cells after the disappearance of the *Anabaena* bloom.

Figure 8 . Comparisons of Seasonal Variations in Selected
Chemical Conditions and Water Temperature in 1966 and 1967
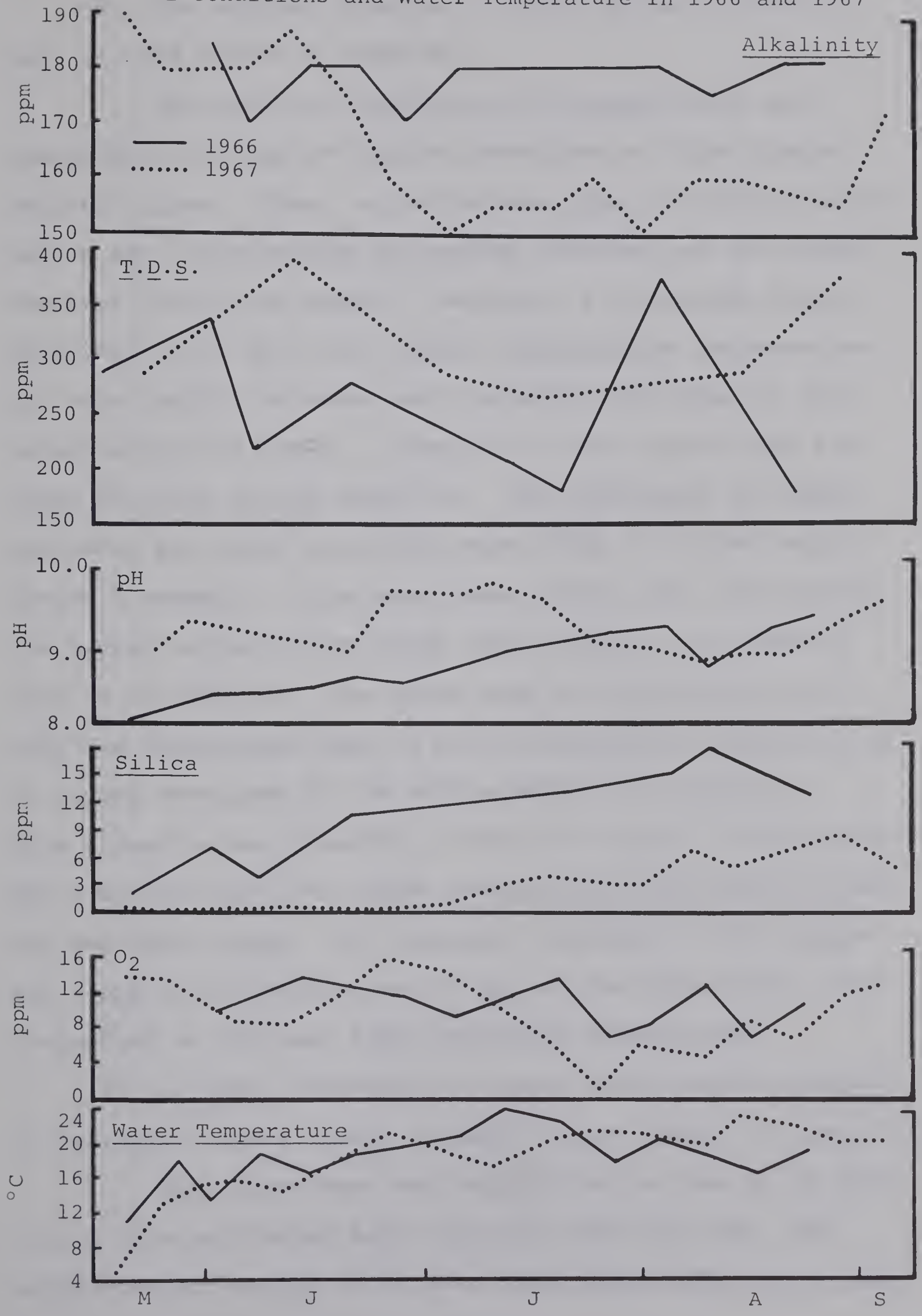
B.   The Vertical Profile of Oxygen Content (Table 6, page 55, and Figure 9, page 56).

The vertical distribution of oxygen which was investigated during 1967 may be described as three characteristic types. First, an orthograde type of uniform distribution was formed during the spring turnover and was seldom observed during the summer. Secondly, a clinograde type of distribution in which the oxygen concentration decreases as the water depth increases was frequently developed in this water during the summer. Examples of this second type are shown for June 26 and August 21. The occurrence of oxygen depletion was found relatively more often in bottom waters (below 5 meters). In extreme cases, which were not unusual, the oxygen in the bottom water fell to zero, e.g. March 3, July 17 and July 24. The third type of distribution is a positive heterograde type in which the maximum concentration of oxygen developed in the middle depths, or nearly so. This situation was observed on June 19, August 15 and September 5 during which the oxygen maxima were established around the one meter depth. For instance, on August 15 the oxygen was 9 ppm on the surface and 13 ppm at one meter depth, corresponding to 105% and 150% saturation respectively.

C.   Diurnal Variation in Oxygen Concentration Related to Different Depths (Table 7, page 57, and Figure 10, page 58).

This experiment was carried out on June 26 of 1967. During this particular day, which was warm and calm, the oxygen content seemed to be in a stratified condition in the

TABLE 6

Vertical Variation in Dissolved Oxygen at Station A

for Selected Dates of 1967

DEPTH	March 3	June 19	June 26	July 10	July 24	Aug. 15	Aug. 21	Sept. 15
Surface	2.6	12.5	16.4	10.6	1.2	9.2	7.0	13.0
1 meter	2.3	13.5	14.2	10.4	1.2	13.0	–	14+
2 "	–	13.0	–	–	–	10.5	6.2	8.4
3 "	1.1	12.0	9.5	10.2	0.8	11.0	–	–
4 "	–	12.0	–	–	–	7.5	4.2	8.4
5 "	–	12.0	6.4	10.2	nil	0.4	0.5	7.2
6 "	–	10.5	–	–	–	0.2	–	3.6

DISSOLVED O_2

Figure 9. Vertical Distribution of Dissolved Oxygen for Selected Dates at Station A, 1967
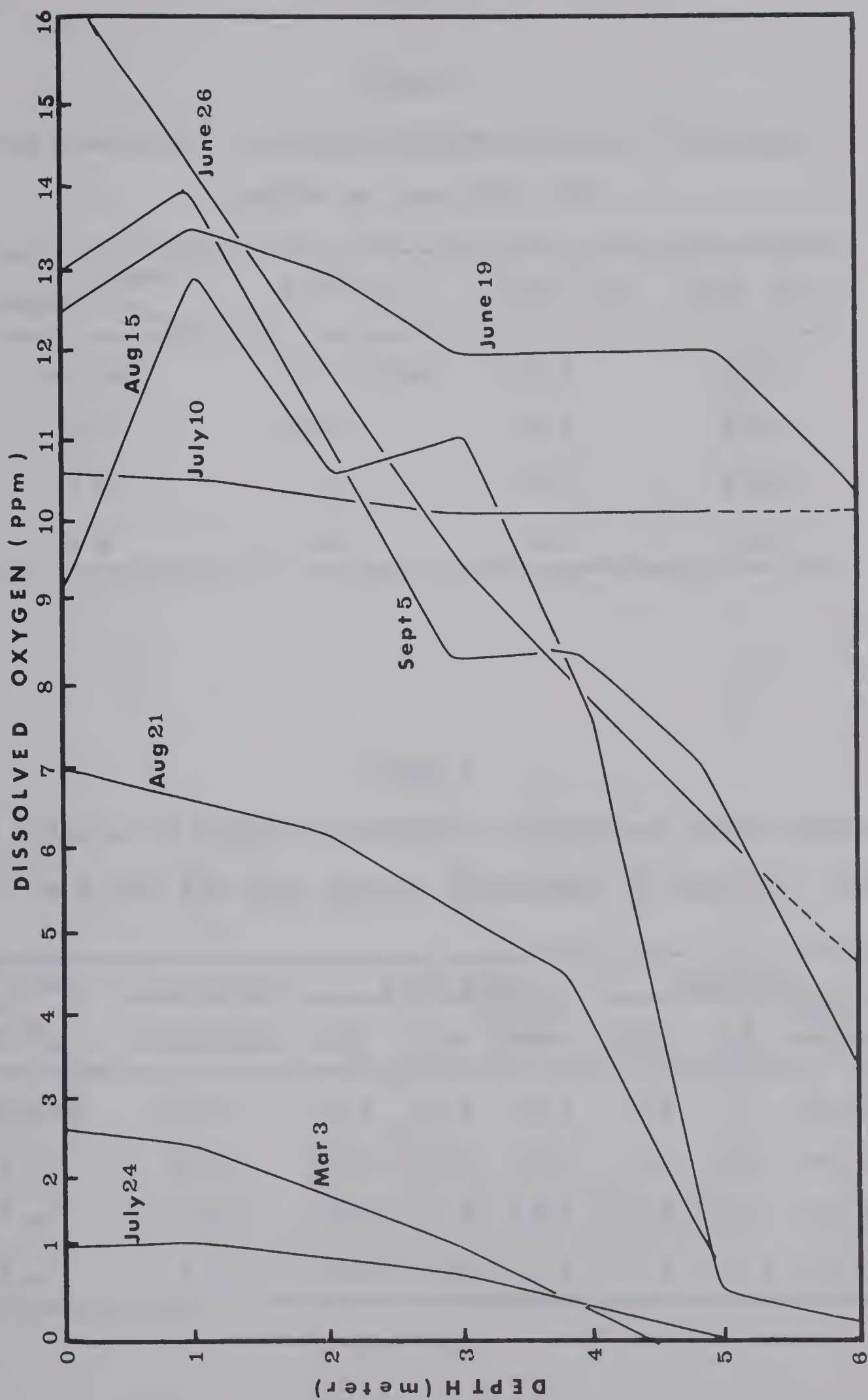
TABLE 7

The Variation in Oxygen Concentration at Different

Depths on June 26, 1967

Depth \ Time	4:00 a.m.	11:00 a.m.	4:00 p.m.
Surface	13.1 (ppm)	16.4	20.6
1 m	12.2	14.2	17.3
3 m	7.1	9.5	12.3
5 m	3.6	6.4	3.8

TABLE 8

The Balance of Dissolved Oxygen in Different Water Depths

from the Light and Dark Bottle Experiment on June 26, 1967

Depth \ Time	10:30 a.m. (initial)	4:00 p.m.			Balance		
		L.B.	D.B.	Lake Water	L.B.	D.B.	Lake Water
Surface	16.4	14.6	11.0	20.6	-1.8	-5	+4.2
1 m	14.2	13.6	13.0	17.3	-0.6	-0.5	+3.1
3 m	9.5	8.6	8.0	12.3	-0.9	-1.5	+2.8
5 m	6.4	7.5	7.5	3.8	-1.1	+1.1	-2.6

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Figure 10. The Stratification of Dissolved Oxygen in the Daytime on June 26, 1967
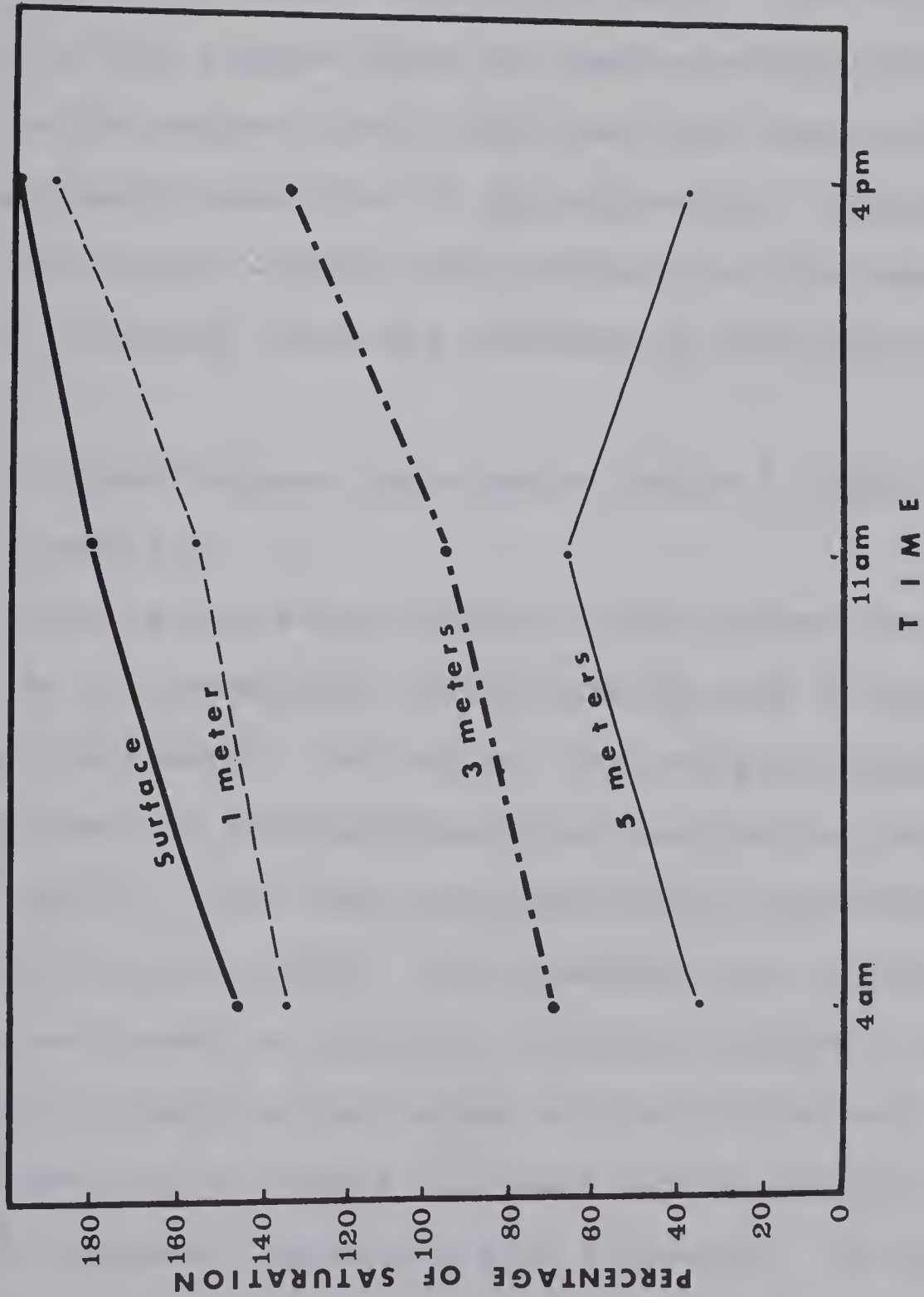
water column. In the upper layer of the water (surface to
1 meter) oxygen in concentrations as great as 140% were
recorded almost all day long with a maximum value of over
180% at 4:00 p.m. The transparency from the Secchi disk
reading was only 40 cm which indicates that the light illumi-
nation was greatly reduced below this depth. The oxygen
saturation at the 3 meter depth was approximately half as
great as in the surface water which may have been due to the
presence of small quantities of phytoplankton. A convex
curve of the diurnal oxygen concentration in five meter water
shows that a maximum value was produced in the middle of the
day.

D. Oxygen Balance Experiments (Table 8, page 57 and
Figure 11, page 60).

Most of the water column in this holomictic lake is
inhabited by a tremendously large standing crop of phytoplank-
ton during the summer. The oxygen loss and gain resulting
from the process of photosynthesis and respiration vary at
different depths. The light and dark bottle experiment was
conducted on June 26, 1967. The experiment was initiated at
10:30 a.m. and ended at 4:00 p.m. Figure 11 shows a series of
determinations based on the values of the initial and final
oxygen concentrations within 5.5 hours during the day. The
changes at different depths are also indicated. In both the
light and dark bottles, the oxygen consumption was greater
than production at most levels except in the water below
4 meters. In the dark bottle the greatest loss of oxygen

Figure 11. The Changes of Dissolved Oxygen in Different Depths from the Results of Light and Dark Bottle and Open Lake Water on June 26, 1967
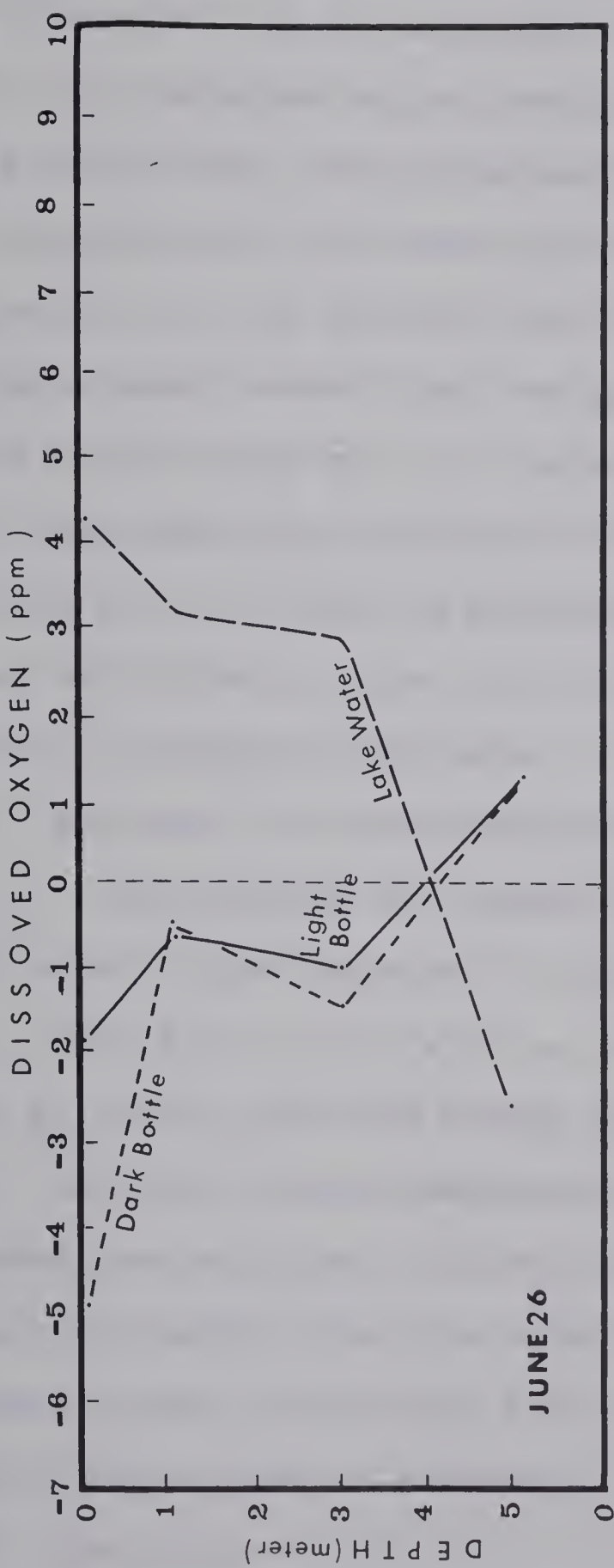
was in the upper layer of the water in which the oxygen loss was 5 ppm. On the other hand, the light bottle also lost 2 ppm in the same period of time. This is presumably due to the shortage of CO_2 in the light bottle preventing the great number of blue-green algae from photosynthesizing efficiently. On the other hand, the phytoplankton in the surface water was well supplied with CO_2 from the atmosphere. Therefore the production of O_2 is greater than that which was being consumed. This experiment showed that the approximate compensation point was developed at the 1 meter water depth. Hutchinson (1957) mentioned that according to Yoshimura the compensation point may be calculated by multiplying the transparency depth reading of the Secchi disk by 1.2. However, this experiment seems not to support this idea.

2. Hydrogen Ion Concentration

The hydrogen ion concentration on the surface varied within a pH range of 8.0 to 9.5, with an average of 8.8 in 1966; 8.9 to 10.0 with an average of 9.3 during 1967. A high pH value indicates strong alkaline reaction in this water. This was evident especially during those days of increased photosynthetic activity which resulted in the removal of free CO_2 from the water. In most natural, shallow water bodies, in Astotin Lake there was a slight fall in the pH at the bottom of the lake.

3. Alkalinity

In 1966 the total alkalinity fluctuated from 170 to 185 ppm with a mean of 178 ppm, while during 1967 the

range was from 150 to 190 ppm with a mean of 168 ppm. A

value of 250 ppm was recorded in the ice covered water on

March 3, 1967. Some remarkable changes in both carbonate

and bicarbonate alkalinity occurred in the ice-free water.

Generally, the removal of free CO_2 from the water by phyto-

planktonic assimilation caused increased carbonate alkalin-

ity and decreased bicarbonate alkalinity. This is the

reason why the algal bloom was always accompanied by a sud-

den drop in the concentration of bicarbonate alkalinity.

A considerable amount of bicarbonate was dissociated to sup-

ply the CO_2 source. The bicarbonate alkalinity dropped to

110 ppm on June 26 from 150 ppm, the latter reading being

taken on June 19. In the same period of time, the carbonate

alkalinity increased 25 ppm. *Anabaena spiroides* var. *crassa*

bloomed during this period and was likely responsible for

this phenomenon. A similar pattern of bicarbonate-carbonate

change was observed frequently throughout the summer of 1967.

    4. Hardness

        During 1966 the mean total hardness was 165 ppm

with a range of 155 to 175 ppm. The calcium hardness was

about 60% of the total hardness on the average, with minimum

and maximum values of 80 and 110 ppm respectively. There was

much more seasonal fluctuation in both total hardness and

calcium hardness during the year of 1967. The total hardness

ranged from 115 to 185 ppm, and the calcium hardness ranged

from 50 to 100 ppm with a mean of 71.4 ppm. During the

Anabaena bloom from June 19 to June 26 the total hardness

dropped to 115 ppm from 160 ppm. The calcium hardness drop-
ped to 50 ppm in the same period of time. Because of their
close relationships with CO_2, alkalinity and hardness fluc-
tuated in almost similar patterns.

5. Total Dissolved Solids (T.D.S.)

The total dissolved solids ranged from 169.0 to
376.0 ppm with a mean of 281.0 ppm in 1966, and from 178.0 to
482.0 ppm with a mean of 313.0 ppm in 1967. A series of
relatively low concentrations of T.D.S. was recorded in July
of both years. This low value is likely due to the occur-
rence of immense water blooms of blue-green algae which take
up the dissolved organic and inorganic substances from the
water. The decomposition of bottom deposits during the win-
ter sharply increased the T.D.S. in the water during the
period after surface water freeze-up. The maximum concentra-
tion was recorded in March 1967 almost four months after ice
cover.

6. Dissolved Inorganic Substances

Silica: The silica concentration varied greatly,
not only seasonally but also annually. In 1966 the silica
concentration fluctuated in a wide range from 0.25 to 15.0
ppm and averaged 8.36 ppm. In 1967 it ranged from 0.0 to
8.5 ppm with a mean of 2.6 ppm. A number of relatively low
concentrations were recorded in late spring and fall.

Ortho-phosphate phosphorus: Much higher concentra-
tions of ortho-phosphate were recorded in 1966 than in 1967.
The ortho-phosphate was present in a range of 0.19 - 1.2 ppm

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with a mean of 0.83 ppm in 1966, and of 0.2 - 1.0 ppm with a
mean of 0.4 ppm in 1967. Extremely low concentrations were
recorded in the summer of 1967 when the blue-green algal
blooms occurred.

Nitrogen: Both nitrate nitrogen and nitrite nitro-
gen were recorded constantly and gave readings of zero
throughout the entire study period, except for one reading
of 2.6 ppm for nitrate nitrogen on December 20, a month after
freeze-up.

Iron: The concentration of iron ranged from 0.0
to 1.0 ppm and from 0.0 to 0.3 ppm in 1966 and 1967, res-
pectively. These low concentrations were recorded during
the summer periods.

7. Organic Matter

The range of organic matter concentration was 21.1 -
102.0 ppm and 57.0 - 121.0 ppm in 1966 and 1967 respectively.
The mean concentration of 1967 was 85.1 ppm which was twofold
greater than that of 1966.

8. Description of Bottom Deposits

In a microscopic examination of the bottom deposits
two kinds of sediments can be recognized according to origin.
First, the autochthonous sediments which are formed from the
lake biota, i.e. the sediments of plant and animal remains
from the community of the lake along with their inorganic
and organic integuments and supporting materials. Secondly,
the allochthonous sediments which are derived from material
introduced from outside the lake. The dust, pollen grains

and fallen leaves etc., which contribute to the sediments of
this lake are introduced material. Astotin Lake, with a re-
latively small inflow of surface water from its watershed,
contains primarily autochthonous sediments. Except for a
few small areas with sandy deposits, the lake bottom is
formed by finely divided sediments of grey to greyish-brown
color which at times have an elastic consistency. This
type of sediment is referred to as gyttja.

Some results of analyses of bottom sediments are
given in Table 9, page 66. According to these data, the
chemical composition of the lake sediments is highly hetero-
geneous, except for potassium. Unfortunately, the casual
samples and rather simple analysis are not adequate to en-
able one to draw conclusions about the chemical features
of the bottom sediments in this lake.

III Biotic Features

1. Aquatic Macrophytes

The growth of aquatic macrophytes in Astotin Lake
was recorded in most parts of the water in which the depth
was less than four meters. Generally, the most dense growth
occurred during the late summer. During the study period
12 species of vascular plants and a few species of filamen-
tous green algae were identified. This macroscopic aquatic
vegetation may be categorized into three assemblages accord-
ing to their life forms. The distribution of these forms
in the lake is shown in Figure 12, page 67.

TABLE 9

The Results of Chemical Analysis of the Bottom Sediments in Astotin Lake from Samples Collected during the Summers of 1966 and 1967

Station	Nutrients (lb per acre)				Organic Matter	Free Lime	Soil Reactions	
	N	P	K	SO₄			pH	Conductivity
1966								
High Island	1	83	600	low	medium	nil	7.3	2.6
1967								
High Island	9	41	600	medium	VL	nil	7.3	2.6
North Bay	5	15	600		VL	L	7.5	0.8
South Long Island	4	2	468		VL	M	8.0	0.9
Beach	2	36	596		VL	nil	7.6	1.3

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Figure 12.   Map of Astotin Lake Showing the Extent of the
Zones of Floating, Emergent and Submerged Aquatic Macrophytes
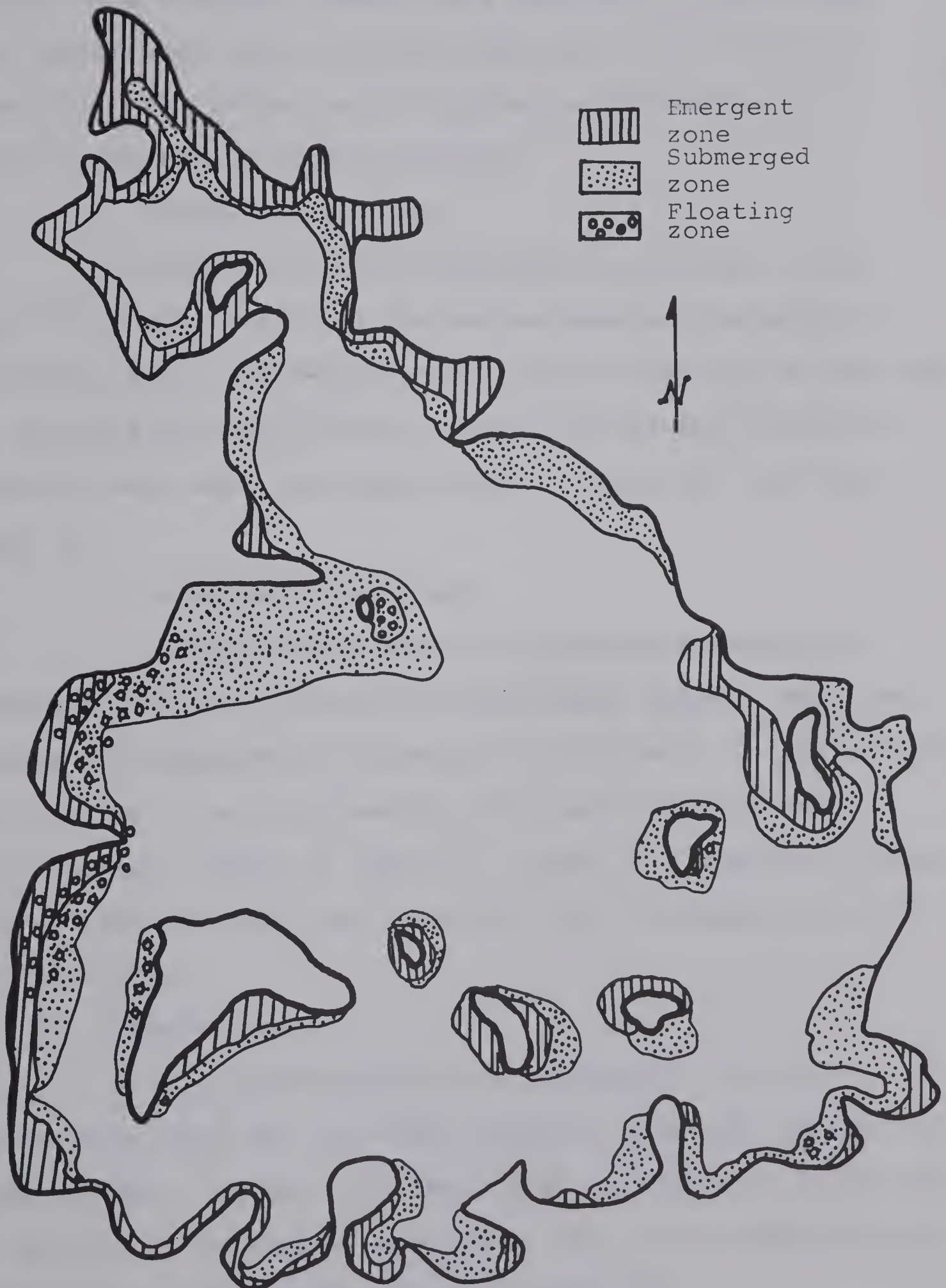
A.   Floating Assemblage

Plants with entirely floating bodies, and rooted plants with floating leaves are classified in this group. The former were *Lemna trisulca* and *Lemna minor* (Plate 1, page 69). The latter were *Polygonum amphibium* var. *stipulaceum* and *Sagittaria cuneata*.

B.   Emergent Assemblage

Typha latifolia, *Sparganium eurycarpum*, *Carex aquatilis*, and *Scolochloa festucacea* were most abundant in littoral areas. In deeper water areas, which may be referred to as the sublittoral zone, *Scirpus validus* and *Phragmites communis* were well developed (Plate 2, page 69; and Plate 3, page 70).

C.   Submerged Assemblage

A continuous growth of submerged macrophytes extended from the littoral to sublittoral zones. This community was composed of *Potamogeton filiformis*, *P. richardsonii*, *P. pusillus*, *Ceratophyllum demersum*, and *Myriophyllum verticellatum* (Plate 4, page 70). Mats of filamentous green algae *Cladophora* spp. and *Mougeotia* sp. stretched along the littoral zone.

2. Aquatic Fauna

Large populations of sticklebacks (*Culacea inconstaus*) were the only fish found in this lake during the study period. In spite of their high tolerance to this water of pronounced eutrophic conditions, they still suffered from summer-kill occasionally (Plate 5, page 71).

Plate 1. Floating *Lemna minor* in July 1967

Plate 2. Emergent *Scirpus validus* in August, 1967

Plate 3. Emergent *Phragmites communis* in August, 1967

Plate 4. Submerged aquatic macrophytes, mostly *Potamogeton* spp. in August, 1967

Plate 5. Numerous sticklebacks (*Culaea inconstaus*) suffered

from summer-kill and were washed out on the beach,

July 27, 1967

Snails (*Lymnaea stagnalis*, *Physa heterostropha* and *Helisoma trivolvus*) were the main macroscopic benthic fauna.

As far as the zooplankton are concerned, four clado-ceran genera (*Bosmina*, *Chydorus*, *Daphnia* and *Ceriodaphnia*), three copepod genera (*Diaptomus*, *Paracyclops* and *Cyclops*), and one rotifer genus (*Keratella*) were recognized. *Keratella* and *Daphnia* were the dominant genera in the zooplankton dur-ing most of the summer. Large numbers of *Gammarus lacustris* were found in the spring and fall.

In addition to the aquatic animals mentioned above, more than ten species of waterfowl have been recognized on this water during the summer season. Of these birds, the red-necked grebes (*Podiceps grisegena*), American coot (*Fulica americana*), mallard (*Anas platyrhynchos*) and the blue-winged teal (*Anas discors*) are the most important species in terms of numbers. Unfortunately, no reliable information on the numbers of these species of ducks was available to aid in estimating the effect of their presence upon the fertilization of the habitat.

3. Benthic Algae

In an attempt to study the benthic algae in this habitat a series of weekly examinations of bottom sediments and glass slides, suspended in the water, were carried out during the summer of 1966. Eighteen species of algae were recorded from those examinations. They are: *Asterionella* sp., *Cerasterias* sp., *Ceratium* sp., *Cocconeis* sp.*, *Cyclotella* sp., *Cymbella* sp.*, *Melosira* sp., *Gyrosigma* sp.*,

Navicula sp., *Nitzschia* sp., *Pediastrum boryanum*, *Pinnularia* sp.*, *Scenedesmus quadricauda*, *Staurastrum* sp., *Stephanodiscus* sp., *Synedra* sp., *Tetraëdron minimum*, and *Tribonema* sp.* Many species of these algae were recorded as euplanktonic members, at least, they grew in considerable numbers plank- tonically and seasonally. However, some of them such as *Melosira* sp., *Scenedesmus* sp., and *Nitzschia* sp., which may continue their vegetative growth benthically, are considered as meroplankton. The species which have an asterisk (*) are those which grew on the sediments, and are known as benthic forms. In addition to those algae found on the sediments, some colonial species such as species of *Gloeotrichia*, *Stigeoclonium*, and *Coleochaete* were observed growing as epiphytes or epilithic types.

RESULTS OF PHYTOPLANKTON STUDIES

I Species Composition

Some seventy-two species of planktonic algae have
been determined during the study period. Of these, forty-two
species are classified as Chlorophyta, six as Euglenophyta,
ten as Chrysophyta, one as Pyrrophyta and thirteen as Cyano-
phyta. As to the time of their occurrence, forty-seven spe-
cies were recorded in 1966, forty-nine in 1967 and thirty-
three occurred during both years.

Table 10, page 75 indicates the main period of
occurrence and relative abundance of these various phyto-
plankton species. The classification followed is that pro-
posed by Smith (1950).

II Community Succession

A biotic community is defined as "an aggregation
of living organisms in any given area having mutual relation-
ships among themselves and to their environment". The ter-
restrial plant communities such as forest communities and
grassland communities are designated by concrete stands of
those species of trees, grasses, etc. which appear homogene-
ously over a given area. In aquatic environments such con-
spicuous large plants are often lacking and thus the organ-
isms of other life forms in the habitat must serve this pur-
pose. For example, in some lentic environments the communi-
ties may conveniently be named after the species of phyto-
plankton which occupies the habitat homogeneously and

TABLE 10

Species Composition of Phytoplankton with Notes on

their Time of Occurrence and Relative Abundance

Taxa	Period of Occurrence	Relative Abundance**
CHLOROPHYTA		
Chlorophyceae		
Chlamydomonaceae		
Chlamydomonas globosa Snow.	a.* June and October b.* May	rare to abundant common
Phacotaceae		
Phacotus lenticularis (Ehrenb.) Stein.	a. August – October b. May to June	rare rare
Volvocaceae		
Eudorina elegans Ehrenberg.	a. September – October b. June	rare rare
Volvox aureus Ehrenberg.	a. June	rare

*a. indicates data for 1966 and b. for 1967
** rare——less than 50 cells per millilitre, common——50 to 500 cells/ml, abundant———
   more than 500 cells/ml, bloom——more than 5000 cells/ml

Palmeliaceae

Sphaerocystis schroeteri Chodat.
a. June – July — abundant
b. July — rare

Asterococcus limneticus G.M. Smith.
a. June — rare

Coccomyxaceae

Elakatothrix gelatinosa Wille.
a. October — rare
b. June — rare

Micractiniaceae

Golenkinia radiata (Chod.) Wille.
b. June and August — rare

Micractinium pusillum Fresenius.
b. June — rare

Dictyosphaeriaceae

Dictyosphaerium ehrenbergianum Naegeli.
b. June – July — rare to abundant

Characiaceae

Characium ambiguum Hermann.
a. June — rare

Schroederia judayi G.M. Smith.
a. June – August — rare
b. July — rare

Hydrodictyaceae

Pediastrum boryanum (Turp.) Meneghin.
a. June – November — rare to common
b. May – July, Aug., Sept. — abundant

Pediastrum duplex Meyen.
a. May – July — common

Species		Months	Abundance
Pediastrum duplex var. *clathratum* (A. Braun) Lagerheim.	b.	May - July	rare to common
Pediastrum tetras (Ehrenb.) Ralfs.	b.	June and July	rare
Caelastraceae			
Coelastrum microporum Naegeli.	b.	July to September	abundant
Oocystaceae			
Ankistrodesmus falcatus (Corda) Ralfs.	b.	July to September	abundant
Closteriopsis longissima Lemmermann.	b.	June and July	rare
Cerasterias staurastroides West and West.	a.	June, September - October	rare
	b.	June	rare
Lagerheimia quadriseta (Lemm.) G. M. Smith.	b.	June	rare to common
Oocystis crassa Wittrock.	a.	June	rare
	b.	June - September	common to abundant
Lagerheimia longiseta (Lemm.) Printz.	b.	June and July	rare
Oocystis borgei Snow.	a.	June - August	rare
	b.	June - August	common
Planktosphaeria gelatinosa G. M. Smith.	a.	June - July	rare

Species		Period	Abundance
Quadrigula chodatii (Tanner-Fullman) G. M. Smith.	a.	June and September	rare
Quadrigula lacustris (Chod.) G. M. Smith.	a.	July	rare
Selenastrum westii G. M. Smith.	b.	June and July	common and abundant
Tetraëdron minimum (A. Braun) Hansgrig.	a.	June to September	rare
	b.	June to September	rare to common
Tetraëdron muticum (A. Braun) Hansgrig.	a.	September	rare
	b.	June to September	rare to common
Scenedesmaceae			
Actinastrum hantzschii Lagerheim.	a.	October and November	common
	b.	May to July	common
Crucigenia apiculata (Lemm.) Schmidle.	b.	May	rare
Crucigenia rectangularis (A. Braun) Gay.	b.	May and July	common
Scenedesmus acuminatus (Lag.) Chodat.	b.	August	rare
Scenedesmus abundans var. *asymmetrica* (Schroed.) G. M. Smith.	b.	June – August	common
Scenedesmus bijuga var. *alternans* (Reinsch) Borge.	b.	July – August	occasionally

Species		Month	Abundance
Scenedesmus dimorphus (Turp.) Kuetzing.	a.	August to September	common
	b.	June to September	common
Scenedesmus quadricauda (Turp.) Brebisson.	a.	May to June, July, August – November	rare to abundant
	b.	May to September	common to abundant
Scenedesmus quadricauda var. *westii* G. M. Smith.	a.	November	common
	b.	July	rare
Desmidiaceae			
Closterium sp.	a.	June and August	rare
Cosmarium sp.	a.	June to July	occasionally
	b.	July	common
Staurastrum gracile Ralfs.	a.	May and September	rare
	b.	June	occasionally
EUGLENOPHYTA			
Euglenophyceae			
Euglena sanguinea Ehrenberg.	a.	June to July	rare
	b.	May and June	rare to common
Euglena polymorpha Dangeard.	a.	June	rare
	b.	May	rare
Phacus pyrum (Ehrenb.) Stein.	a.	September	rare
Phacus nordstedii Lemmermann.	b.	May	rare

Trachelomonas similis Stokes.   b.   May to June   rare to common

Trachelomonas volvocina Ehrenberg.   b.   May to June   rare

CHRYSOPHYTA

Xanthophyceae

Gloeobotrydiaceae

Gloeobotrys limneticus (G. M. Smith) Poscher.   a.   June   rare

Chrysophyceae

Ochromonadaceae

Dinobryon sertularia Ehrenberg.   b.   June to July   rare to common (locally distributed)

Bacillariophyceae

Coscinodiscaceae

Cyclotella meneghiniana Kuetzing.   a.   May to June   common
   b.   May to June   bloom

Melosira italica (Ehrenb.) Kuetzing.   a.   May to June, July, September to November   rare to bloom
   b.   May to September   rare to abundant

Stephanodiscus astraea (Ehrenb.) Grunow.   a.   July, August, September to November   rare to common
   b.   May to September

Fragillariaceae

Asterionella formosa Hassall.
a. May to June, July, August, September to November — rare to common

Synedra acus Kuetzing.
a. June, September to November — rare
b. May to August — rare to common

Naviculaceae

Navicula oblonga Kuetzing.
a. July — rare
b. June, September — rare to common

Pinnularia viridis (Nitzsch) Ehrenberg.
a. June — rare

Nitzschiaceae

Nitzschia palea (Kuetz.) Wm. Smith.
a. July, August to November — rare to abundant
b. June to September — common to abundant

PHRROPHYTA

Dinophyceae

Ceratiaceae

Ceratium hirundinella (Muell.) Schrank.
a. May, July to August, September — rare
b. Occasionally — rare

CYANOPHYTA

Myxophyceae

Chroococcaceae

Aphanocapsa pulchra (Kuetz.)
Rabenhorst.   a. June   common

Chroococcus dispersus (Keis.)
Lemmermann.   a. August   common

Chroococcus limneticus
Lemmermann.   a. August   common

Chroococcus minor (Kuetz.)
Naegeli.   a. August to September   rare to abundant

Coelosphaerium naegelianum
Unger.   b. July   rare

Coelosphaerium pallidum
Lemmermann.   b. July   rare to common

Merismopedia convoluta Brebisson.   a. August   common

Synechocystis aquatilis
Saurageau.   a. August   common

Microcystis aeruginosa Kuetzing.   a. June to August   common to bloom
                                         b. June to September common to bloom

Nostocaceae

Aphanizomenon flos-aquae
(Linn.) Ralfs.   a. June to August   common to bloom
                                         b. June to September common to bloom

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Anabaena circinalis (Kuetz.) Rabenhorst.

a. June to September — rare to slight bloom
b. June to July — common to bloom

Anabaena spiroides var. *crassa* Lemmermann.

b. June to July, August to September — common to bloom

Rivulariceae

Gloeotrichia echinulata (J. E. Smith) P. Richter.

a. July — common (locally distributed)

abundantly. Basically, this study deals with tiny, rapidly

dividing organisms which may produce numerous generations dur-

ing the course of an annual growth. As well, the species

composition in a given body of water may vary considerably

with seasonal changes. If this large number of generations

and great variation of species composition were converted to

terrestrial communities, an equivalent number of thousands

of years would be involved in the successional history.

This point of view gives a picture of the phytoplankton as

an ever-changing community at any given moment in a particu-

lar aquatic environment.

Generally, the dominant species in a community

occupies a more significant niche than the species that are

present rarely or never abundant. In other words, the nature

of a community and some features of the ecosystem in which

the phytoplankton occur may be characterized by its dominant

species. Therefore, in attempting to classify the phyto-

plankton communities the name of the dominant species, or

sometimes the dominant and the subdominant, will be used as

a designation for the community. Ideally, the dominant spe-

cies must be considered numerically, volumetrically and

physiologically. However, the physiological aspect is

beyond consideration in this study because of its complexity.

The seasonal succession of the dominant species of

phytoplankton communities which occurred in Astotin Lake dur-

ing the study period are illustrated by Figure 13, page 85.

No clear-cut boundaries between communities can be drawn,

Figure 13. Distribution of Populations of Dominant Species of Phytoplankton Communities for the Period Mid-May to Mid-November 1966 and Mid-May to Early September 1967.

a. *Asterionella formosa* community, b. *Anabaena circinalis* community, c. *Microcystis aeruginosa - Aphanizomenon flos-aquae* community, d. *Microcystis aeruginosa - Nitzschia* sp. community, e. *Melosira italica* community, f. *Cyclotella meneghiniana* community, g. *Anabaena spiroides* var. *crassa - Anabaena circinalis* community, h. *Microcystis aeruginosa - Aphanizomenon flos-aquae* community, i. *Microcystis aeruginosa* community

PER CENT OF DOMINANCE
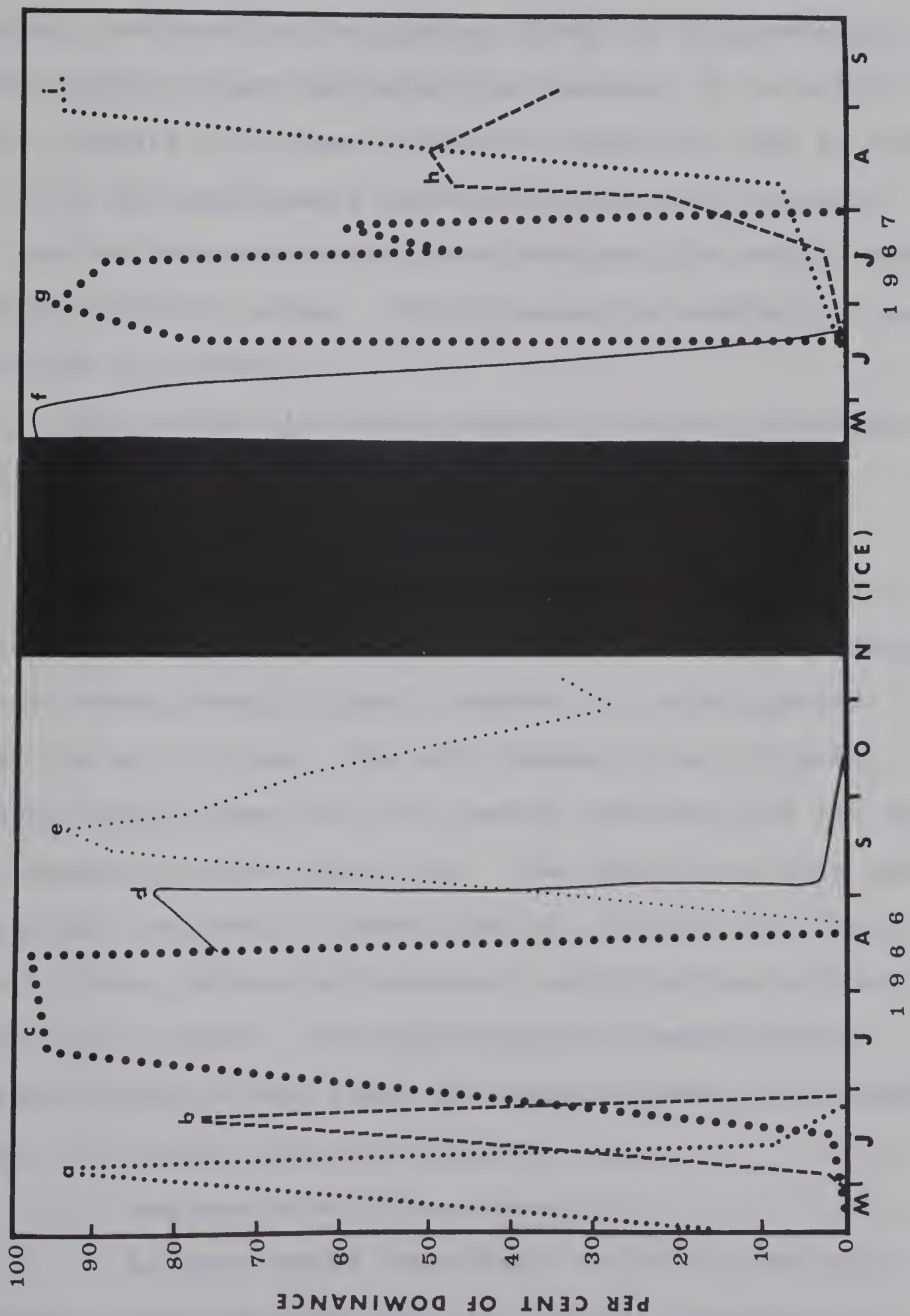
and thus the distribution of component populations may be referred to as a "continuum" type. This community overlapping is attributed to the gradual change in environmental factors which occurs throughout the season. It is worthwhile to state that these curves of Figure 13, page 85 represent only the approximate population growth of the dominant species because the data were obtained from weekly samples on arbitrary dates. The phytoplankton communities are described as follows:

1. The Communities Which Occurred from May to November of 1966

    A. *Asterionella formosa* Community

        Four species of diatoms *Asterionella formosa*, *Cyclotella meneghiniana*, *Melosira italica* and *Stephanodiscus astraea* were present in small numbers in a short period after the spring thaw. The cell numbers of *Asterionella formosa* rapidly rose and this species accounted for 91% of the community by the end of May. The other 9% of this community was composed of eleven species, of which *Cyclotella meneghiniana*, *Pediastrum boryanum*, and *Tetraëdron minimum* were always present. This spring diatom community disappeared within a week after the maximum growth of its dominant, *Asterionella formosa*, declined.

    B. *Anabaena circinalis* Community

        An accelerated increase of *Anabaena circinalis* occurred during mid-June, and this species accounted for 77% of the cells in this community. Meanwhile, the species

Pediastrum boryanum, *Sphaerocystis schroeteri* and *Schroederia judayi* were in relatively large numbers among the nine minor species. This community dissociated at the end of June. In terms of population size, dominance and period of duration, this community was relatively poorly developed.

C. *Sphaerocystis schroeteri* Subcommunity

For convenience of study, the term subcommunity is applied to a community which was dominated by a species which was delimited within the continuum between two communities. After the decline of *Anabaena circinalis*, *Sphaerocystis schroeteri* increased its population to 91% of dominance by June 28 and was associated with 15 other species. *Microcystis aeruginosa* and *Aphanizomenon flos-aquae* were present in abundance. Although *Sphaerocystis schroeteri* developed to its seasonal maximum growth by July 5, the bloom caused by *Microcystis* and *Aphanizomenon* dominated the phytoplankton growth completely.

D. *Microcystis aeruginosa* - *Aphanizomenon flos-aquae* Community

Occurrence of the waterbloom in this summer was caused by these two cyanophycean species, which had appeared in small numbers since early June, started to bloom in early July and bloomed until mid-August. There were six species in this community instead of the 15 species present preceeding its formation. Among these few associate members the species *Ceratium hirundinella* and *Nitzschia palea* were present frequently. *Aphanizomenon flos-aquae* declined greatly,

and *Microcystis aeruginosa* became dominant towards the lag stage of this community. During this period of time, the community increased in species diversity. The autumn pulse of *Anabaena circinalis* occurred in small numbers in the late stage of the *Microcystis-Aphanizomenon* community.

During the second half of August, a mixed and intermediate community occurred as no species developed a population large enough to dominate among the 12 species present. However, *Nitzschia* sp., *Anabaena circinalis* and *Pediastrum boryanum* were present in rather marked numbers, as each of these species occupied 30 to 40% of the community.

E. *Melosira italica* Community

As autumn approached the phytoplankton community in this water was dominated by diatom species. All of the diatom members which had grown during the spring period reappeared in this fall community. *Melosira italica* became dominant beginning in early September and developed to its maximum growth of 94% dominance by September 20. During the course of the *Melosira italica* dominance *Pediastrum boryanum*, *Scenedesmus quadricauda* and *Stephanodiscus astraea* accompanied it in large numbers. In addition, *Chlamydomonas* sp. tended to be sub-dominant at the end stages of this community just before the freeze-up.

2. The Communities Which Occurred for the Period of May to September of 1967

A. *Cyclotella meneghiniana* Community

The spring community was characterized by the

maximum growth of the dominant diatom species, *Cyclotella meneghiniana*, which accounted for 98% of the population of the surface waters on May 23. This high dominance decreased to 79% on June 5. Eight other species associated with *Cyclotella* at the beginning of the development of this community were distinguished. Among those species, *Scenedesmus quadricauda* var. *westii*, *Synedra acus*, *Chlamydomonas* sp., *Melosira italica* and *Crucigenia* sp. were commonly present. After June 5, a more complex species composition developed as the numbers of *Cyclotella meneghiniana* declined. By mid-June twenty-eight species occurred in the latter stages of this community. Of these, the green algae were in the majority. *Scenedesmus quadricauda* and *Dictyosphaerium ehrenbergianum* appeared in abundance.

B. *Anabaena spiroides* var. *crassa* - *Anabaena circinalis* Community

As before, the blue-green algae started to occupy this water as the summer came. The first cyanophycean waterbloom caused by *Anabaena* species occurred from the middle of June until about July 20. A large number of species, which were associated with the previous community during the latter stages, accompanied the dominants during the period from mid-June to the end of the month before the maximum bloom of the dominant species occurred. The occurrence of the maximum bloom, with 95% dominance, was recorded on June 26. During the course of the *Anabaena* bloom more than half of these associate species were

eliminated and eventually, on July 24, there were only twelve species. Those species were chiefly members of the Scenedesmaceae and Oocystaceae, and all of the associate species were recorded in relatively small numbers. Besides the above mentioned species, the latent bloom species *Aphanizomenon* and *Microcystis* were present in abundance throughout the entire period of this community.

C.   Chlorophycean Community

Shortly after the *Anabaena* bloom died off, the phytoplankton community was characterized by a great increase in number of species of green algae. Some twenty-eight species, out of a total of thirty-five species, were recognized as chlorophytes on July 30. Although more than a dozen of these green algal species were present in abundance, none of them became dominant. However, the two most abundant species *Scenedesmus quadricauda* and *Coelastrum microporum* made up 34% of this community. The rapid increase of the blue-green algae *Microcystis* and *Aphanizomenon* seemed to suppress the full development of this chlorophycean community.

D.   *Microcystis aeruginosa - Aphanizomenon flos-aquae* Community

These two dominant species were present in abundance during July and started to bloom at the beginning of August. Again, the non-cyanophycean associate species were considerably reduced both in numbers of species and population size. The declining population of *Aphanizomenon*

species at the end of August made the late summer community
subject to unialgal dominance of *Microcystis aeruginosa*.
During this period, the species *Scenedesmus quadricauda* was
the only associate member which increased steadily.

III Periodicity

Since the phytoplankton consists almost exclu-
sively of unicellular algae, it is convenient to consider
the periodicity of phytoplankton as the quantitative varia-
tion of cell numbers in time. Aspects of algal growth such
as seasonal cycles and growth pulses are shown by these
data.

1. Periodicity of the Phytoplankton Community as a
Whole

Quantitatively, there were marked differences in
the degree of development of phytoplankton between the study
periods of 1966 and 1967, except during the summer period
in which the waterbloom occurred. These differences are
clearly illustrated by Figure 14, page 93 and the details
are tabulated in Table 11, page 92. The annual cycle of
phytoplankton growth in this body of water was character-
ized by the intensive summer waterbloom of blue-green algae.
The growth of massive colonies of these algae made the
accurate count in cell numbers impracticable.

During 1966 the early spring minimum occurred at
the middle of May when the smallest cell number recorded
was 215 cells/ml. A small spring maximum of 2,648 cells/
ml developed in early June and it was followed by a

TABLE 11

Total Individual and Species Number Counts for the

Period of 1966 to 1967

Date 1966		Total Individuals	Species Number	Date 1967		Total Individuals	Species Number
May	18	215	7	May	23	48485	9
June	1	2648	12	June	5	6773	15
	8	372	14		12	5120	31
	21	1161	13		19	24518 (6610**)	19
	28	3087	16		26	41648 (1958**)	25
July	5	4347	15	July	4	(7041**)	
	19	205*	12		10	29109	14
	26	207*	10		17	4160	
					24	4524	9
					31	25092	31
Aug.	3	334*	8	Aug.	7	3627*	21
	11	1629	14		15	3870*	23
	16	936	11		21	4883*	23
	23	640	13		28	7072*	12
Sept.	6	1825	14	Sept.	5	8278*	14
	13	4571	9				
	20	15926	13				
	27	3206	12				
Oct.	12	2178	10				
	24	2154	11				
Nov.	9	884	10				

Note: * These counts do not include individuals of
Microcystis aeruginosa and *Aphanizomenon flos-
aquae* species which were blooming at these times.
** These counts do not include the blooming species
of *Anabaena*.

Figure 14. Comparison of Seasonal Variation in Total Cell Numbers of Phytoplankton between 1966 and 1967

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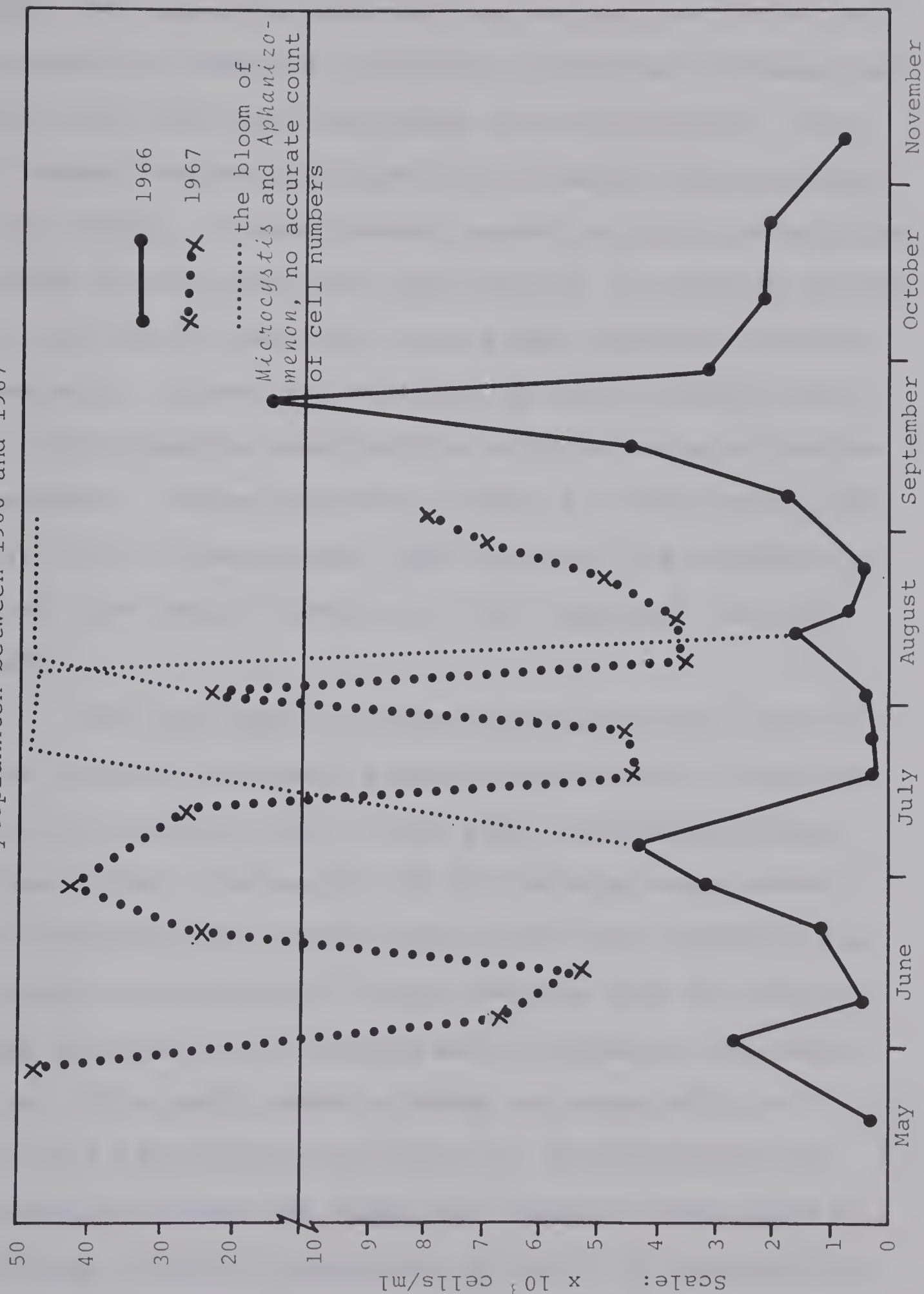
moderate increase after the mid-June depression. After an entire month of moderate increase, an enormous increase took place in July with the occurrence of the waterbloom. The major annual maximum developed in mid-summer from mid-July to early August. A small pulse, caused mainly by chlorphytes, developed shortly after the rapid decline of the blue-greens' bloom, and was followed by a late summer minimum record of 640 cells/ml. After this minimum, an early autumnal maximum of phytoplankton ended with a rapid decrease at the end of September. There followed a rather slow decline in cell numbers until a new minimum (884 cells/ml) was recorded in November just before freeze-up. This completed the cycle for 1966.

The development of the phytoplankton in terms of species diversity and cell numbers was much more intensive during the season of 1967. This year the spring maximum occurred in May. On May 23, 48,485 cells/ml were present as the maximum value of the vernal peak which occurred one week after ice break-up. A rapid decline from the spring maximum resulted in the early summer minimum at the middle of June. This early summer minimum was repeated by a record of 5,120 cells/ml on June 12. The succession of phytoplankton during the summer was greatly diversified by waterblooms of four cyanophycean species. An intermission during the course of the blooms occurred in late July. This was the mid-summer phytoplankton minimum (4,160 cells/ml). Prior to this intermission a remarkable pulse of

Anabaena had occupied the water for almost a month after the mid-June summer minimum. Soon after this same intermission the green algae greatly increased in both species diversity and total cell numbers; an increase which produced a rather short-lived peak at the end of July. Algae were present in considerable numbers as a count of 25,092 cells/ml on July 31 indicates. Eventually, the phytoplankton developed to its annual major maximum, which was maintained from early August until the end of the summer. The scene of this late summer bloom is shown by Plate 6, page 96.

An examination of Figure 14, page 93 between July and August of the years 1966 and 1967 indicates that the summer minima of chlorophytes and diatoms took place almost simultaneously with the occurrence of waterblooms.

2. Periodicities of Particular Species

Of the large number of phytoplankton species which were recognized in this water during the years of 1966 and 1967, some 25 species were comparatively more important in terms of quantity and frequency. According to the occurrence in time of each individual species the phytoplankton are categorized into two major, arbitrary groups. Those species of algae that were present in the phytoplankton community for a period shorter than four weeks are referred to as stenochronic species, and those species that were present for a period of time that exceeded four consecutive weeks are termed eurychronic species (Bozniak 1966). Furthermore, an algal species may exhibit a pulse or pulses during the

Plate 6. A scene of late summer bloom, August 31, 1967.

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course of its annual cycle. A species that exhibits one maxi-mum per year is termed a monacmic species; (mono = one, acmae = peak) where there are two or many maxima, the equi-valent terms diacmic or polyacmic are appropriate (Hutchinson 1957). Combining these aspects namely, the period of time of occurrence, and the frequency of a growth maximum, the phyto-plankton species studied are classified into five groups. The seasonal variations of certain species are illustrated by Figure 15, page 98 and the detailed cell numbers are listed in Table 12, page 99.

A. Stenochronic-Monacmic Species

Most of the species that were rarely present in this lake showed their periodicities in this pattern. *Eurodina* sp., *Phacotus lenticularis* and *Phacus* sp. will serve as examples. Their period of occurrence was less than a month and their maxima showed rather small popula-tion numbers. However, this type of periodicity was also shown by a few species with large populations. For instance, *Cyclotella meneghiniana* exhibited its maximum only once in both the springs of 1966 and 1967 when the cells were recorded as as 112 cells/ml and 5,387 cells/ml, respectively. *Sphaerocystis schroeteri* with its maximum of 4,149 cells/ml in early July of 1966 was also present about a month in the early summer.

B. Stenochronic-Diacmic Species

During 1966 *Asterionella formosa* appeared for three consecutive weeks in the spring and five consecutive

Figure 15.   Periodicities of some Principal Species of

Planktonic Algae from June 1966 to August 1967

	J				J			A				S				O				J				J				A		
	1	8	21	28	5	19	26	3	11	16	23	6	13	20	27	12	24				5	12	19	26	4	10	17	24	31	7	15	21	28

Asterionella formosa

Coelastrum microporum

Cyclotella meneghiniana

Eudorina sp.

Phacotus sp.

Lagerheimia quadriseta

Ceratium hirundinella

Tetraëdron minimum

Scenedesmus dimorphus

Sphaerocystis schroeteri

Melosira italica

Closterium sp.

Dictyosphaerium ehrenbergianum

Stephanodiscus astraea

Nitzschia sp.

Crucigenia sp.

Pediastrum boryanum

Anabaena spp.

Scenedesmus quadricauda

- 0–50 cells/ml
- 50–100 cells/ml
- | 1000 cells/ml

Table 12. Seasonal Variation in Cell Numbers of Selected

Species for the Period 1966 and 1967

Phytoplankton counts by species and sampling date, 1966–1967.

1 9 6 6

Species	May 18	June 1	June 8	June 21	June 28	July 5	July 19	July 26	Aug 3	Aug 11	Aug 16	Aug 23	Sept 6	Sept 13	Sept 20	Sept 27	Oct 12	Oct 24	Nov 9
Asterionella formosa	29	2405	34	-	3	3	-	5	-	9	3	-	3	-	10	71	90	56	41
Cyclotella menengiana	52	112	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Melosira italica	27	12	-	25	4	-	-	13	-	-	-	22	1090	4072	14929	2508	1412	587	303
Stephanodiscus astroea	-	8	-	-	-	4	-	-	5	9	21	116	130	333	196	187	204	-	11
Rhizosolenia	-	-	11	-	-	6	4	13	800	89	370	121	102	31	62	33	20	-	6
Ceratium hirundinella	4	-	-	-	3	3	4	9	89	91	121	53	13	5	-	-	-	-	-
Scenedesmus quadricauda	8	9	-	-	-	4	17	-	-	-	-	59	88	208	270	300	172	366	356
Scenedesmus sp.	-	-	-	-	-	-	-	-	19	-	-	9	-	21	21	16	-	-	31
Pediastrum boryanum	-	34	55	58	-	33	-	40	314	-	50	260	220	125	208	-	226	67	13
Tetraedron minimum	-	4	-	3	-	-	6	-	9	-	9	-	-	52	-	8	-	-	-
Oocystis borgei	-	-	6	-	-	-	10	-	14	-	-	12	28	-	36	25	-	-	17
Sphaerocystis schroeteri	-	-	2	90	-	4149	-	25	-	-	-	-	93	-	-	-	-	-	-
Closterium sp.	-	-	1	-	14	-	-	-	-	-	3	3	-	-	-	-	-	-	-
Chlamydomonas globosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	541	-
Eudorina sp.	-	-	-	-	69	-	-	-	-	-	-	-	10	-	-	-	47	148	-
Phacotus lenticularis	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	8	8	-
Phacus sp.	-	-	-	-	-	-	-	-	-	5	9	-	25	-	-	-	-	-	-
Crucigenia rectangularis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coelastrum microporum	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dictyosphaerium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lagerheimia quadriseta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Anabaena spp.	-	13	893	19	17	-	-	-	28	300	288	171	43	-	-	-	-	-	-

1 9 6 7

Species	May 23	May 29	June 5	June 12	June 19	June 26	July 4	July 10	July 17	July 24	July 31	Aug 7	Aug 15	Aug 21	Aug 28	Sept 5
Asterionella formosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cyclotella menengiana	47611	-	5387	1851	498	-	-	-	-	-	-	-	-	-	-	-
Melosira italica	125	-	357	296	546	31	94	208	42	10	252	166	541	712	1893	853
Stephanodiscus astroea	31	-	29	62	571	-	206	64	42	-	-	-	-	10	-	42
Rhizosolenia	-	-	41	104	182	218	135	-	-	-	1281	125	208	135	541	146
Ceratium hirundinella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scenedesmus quadricauda	248	-	377	520	1206	291	1519	999	808	1134	4774	707	1238	1191	1664	3037
Scenedesmus sp.	-	-	115	166	250	291	406	42	-	83	1323	239	-	-	-	-
Pediastrum boryanum	148	-	148	125	676	-	333	-	310	-	990	-	208	208	-	128
Tetraedron minimum	-	-	-	26	114	52	166	84	42	21	399	84	21	-	42	83
Oocystis borgei	33	-	33	-	447	281	915	322	83	-	231	31	135	135	62	166
Sphaerocystis schroeteri	-	-	-	-	-	-	-	-	-	-	-	-	93	-	-	624
Closterium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlamydomonas globosa	156	-	-	-	-	-	-	-	-	-	798	52	31	52	-	-
Eudorina sp.	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-
Phacotus lenticularis	-	-	12	-	-	-	-	-	-	-	-	-	-	-	-	-
Phacus sp.	-	-	-	21	-	-	-	-	-	-	-	25	-	-	-	-
Crucigenia rectangularis	125	-	-	520	21	166	125	-	82	-	168	915	-	-	-	-
Coelastrum microporum	-	-	-	-	-	62	1487	84	332	333	1344	333	84	374	1830	166
Dictyosphaerium sp.	-	-	863	-	72	21	-	208	-	-	252	-	-	-	-	-
Lagerheimia quadriseta	-	-	57	94	21	-	-	-	-	-	-	-	-	-	-	-
Anabaena spp.	-	-	24518	39690	-	26738	1914	2777	-	-	-	-	-	38	630	75

weeks in the fall. Its populations were 2,405 cells/ml and 90 cells/ml as its major spring maximum and minor autumnal maximum, respectively. The periodicities of certain other species, such as *Scenedesmus dimorphus*, *Chlamydomonas globosa*, *Closterium* sp. and *Lagerheimia quadriseta* were also distributed in this pattern, although occurrence of maxima varied from the seasonal patterns of *Asterionella*.

C. Eurychronic-Monacmic Species

This type of periodicity is represented by *Ceratium hirundinella*, *Microcystis aeruginosa* and *Aphanizomenon flos-aquae*. The latter two species were present in large numbers in the early summer as a pre-bloom potential stage and reached their annual maxima during the mid-summer.

D. Eurychronic-Diacmic Species

A large number of species showed this type of periodicity. The diatoms *Melosira italica*, *Stephanodiscus astraea* and *Nitzschia* sp. tended to exhibit their pulses in the spring and fall, and these two pulses were usually quite unequal in size. *Anabaena circinalis* and *A. spiroides* var. *crassa* were blue-green species that produced a major maximum in the early summer and a minor one in late summer or early autumn. The chlorophytes such as *Crucigenia rectangularis* and *Coelastrum microporum* also demonstrated this type of seasonal periodicity.

E. Eurychronic-Polyacmic Species

Those algae that belong to this group showed irregular pulses (more than two) during the yearly cycle.

This irregularity seems to be associated with the occurrence of a waterbloom rather than seasonal changes. The green algae *Scenedesmus quadricauda*, *Pediastrum boryanum*, *Tetraëdron minimum* and *Oocystis borgei* exhibited this type of periodicity.

IV Spatial Variation

1. Horizontal Distribution

Variation in both the abundance and components of the phytoplankton occurred among stations in this water during the study period. No constant diversity in the plankton populations of different stations was found as the seasons progressed. It is felt that some bias from sampling and enumeration might possibly cause the absence of a few rare species in some samples. For instance, *Asterionella formosa* gave a count of 5 and 9 cells/ml from the samples of July 19 and August 11, respectively, while the count of this species was 0 from the sample of July 26, 1966. Similarly, on June 21, 1966, the number of the same species was recorded as 0 from station A, while it was recorded as 4 and 6 cells/ml for stations B and C, respectively. Such figures may lead to ambiguity in the information concerning these minor organisms.

The results (Table 13, page 102) which refer to abundance and species composition at different stations show that most phytoplankton algae were present at all stations in various population sizes. In other words, the planktonic algae were distributed homogeneously in this lake in terms

TABLE 13

Individual Counts of Phytoplankton Species for Different

Stations in Astotin Lake for Selected Dates

Species	Cell Numbers Per Ml		
June 1, 1966	Station A	Station B	Station C
Asterionella formosa	2405	2902	2106
Cyclotella meneghiniana	112	--	15
Tetraëdron minimum	43	7	5
Pediastrum boryanum	34	163	63
Scenedesmus quadricauda	9	32	6
Stephanodiscus astraea	8	14	5
Quadrigula chodattii	12	51	8
Ankistrodesmus falcatus	6	--	--
Synedra acus	3	10	6
Closterium sp.	2	5	1
Cerasterias staurastroides	2	1	--
Melosira italica	12	--	6
Sphaerocystis schroeteri	--	31	--
	2648	3216	2221
June 21, 1966	Station A	Station B	Station C
Anabaena circinalis	893	7440	24
Tetraëdron minimum	3	--	--
Sphaerocystis schroeteri	90	71	98
Pediastrum boryanum	59	147	150
Schroederia judayi	45	74	47
Nitzschia sp.	11	2	--
Synedra acus	8	--	--
Melosira italica	28	14	9
Oocystis crassa	2	4	10
Asterionella formosa	--	4	6
Closterium sp.	--	--	23
	1139	7756	367

July 7, 1966	Station A	Station B	Station C
Sphaerocystis schroeteri	4149	3037	3411
Schroederia judayi	51	62	66
Planktosphaeria sp.	45	62	15
Pediastrum boryanum	33	65	58
Closterium sp.	14	10	8
Quadrigula chodatii	24	40	62
Anabaena circinalis	7	37	37
Euglena sp.	5	--	2
Ceratium hirundinella	3	--	2
Oocystis crassa	--	4	2
Nitzschia sp.	5	4	--
Scenedesmus quadricauda	4	--	6
Asterionella formos	3	2	--
Melosira italica	--	6	--
	4343	3329	3669

July 19, 1966	Station A	Station B	Station C
Schroederia judayi	85	31	152
Pediastrum duplex	67	--	67
Scenedesmus quadricauda	17	--	50
Tetraëdron minimum	6	--	--
Asterionella formosa	4	--	--
Ceratium hirundinella	4	21	--
Oocystis borgei	2	--	--
Stephanodiscus astraea	4	--	--
Nitzschia sp.	6	5	17
Melosira italica	--	10	23
	195	67	309

* The dominant species *Aphanizominon* and *Microcystis* are not involved in this calculation.

August 3, 1966	Station A	Station B	Station C
Nitzschia sp.	159	187	235
Ceratium hirundinella	91	69	67
Oocystis borgei	28	21	17
Anabaena circinalis	28	18	--
Schroederia judayi	25	25	27
Synedra acus	3	5	13
Synechocystis aquatilis	--	--	101
	334	325	530

August 16, 1966	Station A	Station B	Station C
Nitzschia sp.	370	387	365
Anabaena circinalis	288	396	312
Chroococcus sp.	65	66	64
Ceratium hirundinella	121	103	135
Pediastrum boryanum	50	--	55
Schroederia judayi	19	6	25
Staphanodiscus astraea	9	6	13
Phacotus sp.	9	--	3
Scenedesmus dimorphus	--	37	18
Oocystis crassa	--	13	7
	922	1014	997

June 14, 1967	Station A	Station D	Station E	Station F
Cyclotella meneghiniana	1851	1180	1102	987
Melosira italica	296	156	149	103
Dictyosphaerium spp.	863	411	430	390
Selenastrum westii	280	--	--	15
Scenedesmus quadricauda	520	406	435	463
Scenedesmus dimorphus	166	104	93	118
Nitzschia sp.	104	36	27	34
Stephanodiscus astraea	62	--	6	15
Synedra acus	73	62	51	76
Tetraëdron minimum	26	5	14	8
Tetraëdron muticum	73	130	95	78
Lagerheimia quadriseta	57	16	8	13
Lagerheimia longiseta	94	10	3	25
Oocystis borgei	125	177	120	167
Closteriopsis longissima	62	21	35	5
Pediastrum boryanum	333	224	165	180
Anabaena spiroides var. crassa	--	73	85	--
Crucigenia rectangularis	--	270	85	--
	4985	3281	3002	2755

July 24, 1967	Station A	Station D	Station E	Station F
Anabaena spiroides				
var. crassa	2777	437	3224	3942
Scenedesmus quadricauda	1134	1331	718	790
Scenedesmus dimorphus	83	125	166	129
Oocystis borgei	--	9	9	104
Oocystis crassa	21	10	20	21
Tetraëdron minimum	21	31	32	31
Tetraëdron muticum	--	--	10	42
Closteriospsis sp.	--	62	--	104
Nitzschia sp.	--	31	--	74
Lagerheimia quadriseta	--	21	--	42
Scenedesmus abundans	62	--	42	--
Crucigenia rectangularis	--	--	208	--
Coelastrum microporum	333	333	332	1165
Pediastrum boryanum	--	166	396	--
	4431	2547	5314	6464

July 7, 1967	Station D	Station F	Station E
Anabaena spiroides			
var. crassa	30690	37180	26977
Scenedesmus quadricauda	1082	1206	832
Coelastrum microporum	250	83	250
Scenedesmus dimorphus	125	--	124
Nitzschia sp.	21	31	62
Tetraëdron minimum	52	42	114
Phacotus sp.	--	--	20
Tetraëdron muticum	31	125	52
Stephanodiscus astraea	94	21	20
Melosira italica	52	10	--
Coelosphaerium sp.	--	150	--
Crucigenia rectangularis	--	84	--
	32272	38932	28451

August 21, 1967	Station A	Station E	Station F
Melosira italica	712	1268	863
Scenedesmus quadricauda	1191	1674	1758
Nitzschia sp.	135	416	322
Oocystis crassa	73	--	31
Coelastrum microporum	197	166	666
Closteriopsis longiseta	--	198	104
Navicula sp.	135	84	260
Synedra acus	5	72	21
Tetraëdron minimum	--	84	260
Oocystis borgei	135	114	52
Scenedesmus abundans	104	62	146
Stephanodiscus astraea	10	42	31
Crucigenia rectangularis	915	124	--
Tetraëdron muticum	47	--	--
Coelastrum sphaericum	374	--	--
Sphaerocystis sp.	--	166	--
	4033	4336	4296

species variation. However, one of the most conspicuous facts
about the growth of these algae between stations is the dif-
ferent rates of increase and decrease in population size over
a period of time. Figure 16, page 108 illustrates the total
individuals of the phytoplankton communities distributed at
the different sampling stations and their different fluctua-
tions associated with seasonal changes. For instance, at
station A the cell numbers were recorded as 2,648 cells/ml
on June 1, 1966, they decreased to 1,139 cells/ml on June 21,
and increased to 4,343 cells/ml on July 5. While at station
B the first count of cell numbers was 3,216/ml, and it
increased to 7,756/ml, then decreased to 3,329 cells/ml on
the same dates as indicated for station A. The other fluc-
tuations are also shown by Figure 16, page 108. By analyz-
ing the fluctuations of individual species a more detailed
picture of the specific appearance at different stations can
be drawn. For example, from June 21 to 28, 1966 *Sphaerocystis*
schroederi increased in numbers from 90 to 2,817 cells/ml at
station A, from 71 to 832 cells/ml at station B and from 98
to 229 cells/ml at station C. On June 7, 1967 *Cyclotella* sp.
was recorded as 5,387, 114 and 2037 cells/ml at stations A,
E, F, respectively; while two weeks later it was recorded as
489, 172 and 421 cells/ml for these same stations. Similar
variations were shown by many other species.

There were two species which exhibited evidence of
local distribution during the study period. *Dinobryon*
sertularia occurred at station F on June 7, 1967 when a

Figure 16. Comparisons of the Total Phytoplankton
Numbers of Surface Water between Stations on
Selected Dates, 1966 and 1967
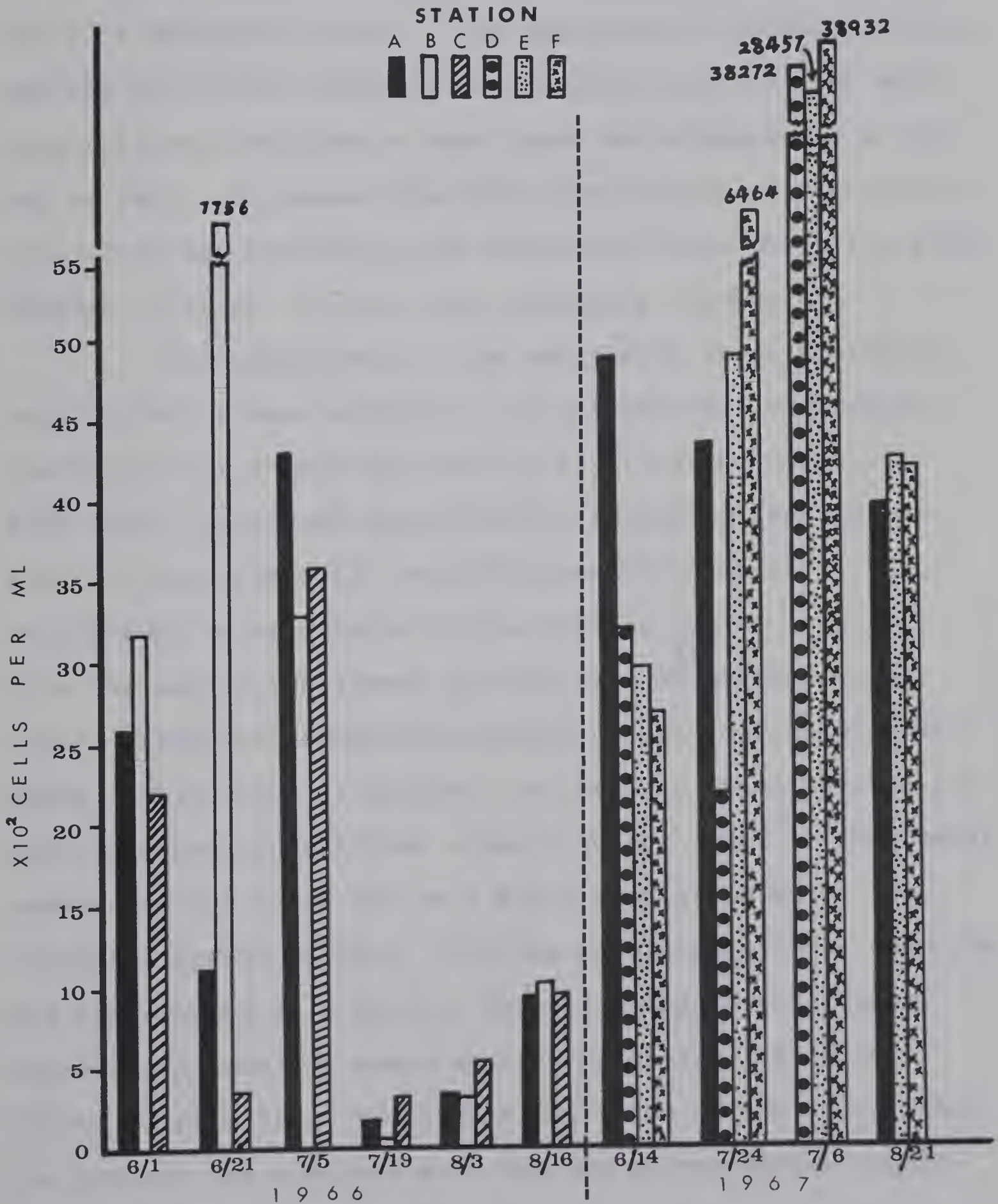
reading of 681 cells/ml was obtained. This species was not observed at any of the other sampling sites. *Gleotrichia echinulata*, one of the blue-green algae, was the other species which had a restricted distribution along the east shore of Raspberry Island. The macroscopic colonies of this species were first observed in the early July of 1966 and a slight bloom took place a week later and disappeared at the end of July. It seemed that the distribution of *Gleotrichia echinulata* was bounded by the particular area where the great bulrush, *Scirpus validus*, grew extremely thickly.

For comparison of the similarity of phytoplankton populations between stations, the mathematical expression coefficient of community (Oosting 1956) may be useful. Kidd (1964) discussed some details concerning the application of this method to the phytoplankton community. The coefficient is calculated by the formula $\frac{2W}{a+b} \times 100$. W is the sum of the lowest of each pair of phytoplankton counts shared in common between two populations being compared. This value is doubled (2W) because those species are shared between populations a and b to the level of the lowest number and the value for an a and b population which are identical should be 100%. The two populations being compared are represented by a and b. The calculated coefficients between stations for some sampling dates are listed in Table 14, page 110. The higher the value of the coefficient the greater the similarity of the two phytoplankton populations.

TABLE 14

Community Coefficients (%) for Different Stations on

Selected Dates during the Study Period of 1966 and 1967

DATE		STATION		
		A and B	B and C	C and A
1966				
June	1	84.6	80.9	89.9
June	21	24.4	9.3	30.4
July	5	83.8	93.1	88.7
July	19	30.53	24.46	75.4
August	3	89.5	75.6	62.0
August	16	86.2	--	95.3

DATE		A and D	A and E	A and F	D and E	D and F	E and F
1967							
June	14	79.8	67.7	67.9	92.7	86.9	88.9
July	6	--	--	--	93.0	93.3	80.8
July	24	51.2	82.2	67.8	19.9	20.5	72.1
August	21	--	61.2	33.3	--	--	78.8

Table 14, page 110 shows that the coefficients range from 9.3% (station B and C June 21, 1966) to 95.3% (stations C and A August 16, 1966). The various degrees of population similarity for the same date among different stations or for the same stations on different dates can be examined. With further examination of the coefficients of Table 14, page 110 one may notice that, whenever the dominant species developed in maximum numbers (often bloomed) the phytoplankton distribution was relatively homogeneous. For instance, on June 1, 1966 the dominant species *Asterionella formosa* developed to a maximum and thus community coefficients between stations were relatively high. The phytoplankton population was heterogeneously distributed over the lake immediately after a blue-green algal bloom disappeared, e.g. on July 24, 1967. This heterogeneity of phytoplankton populations may indicate the localities where the subsequent algal populations mainly originated. However, mechanical factors such as wind always disturbed the distribution of phytoplankton populations to a great extent, especially for the highly buoyant species of blue-green algae. This wind effect may be illustrated by the distribution of *Anabaena circinalis* on June 21, 1966. The cell numbers were recorded as 7,440 cells/ml at station B, 893 cells/ml at station A and 24 cells/ml at station C. These stations were located almost on the longitudinal axis of the lake and the prevailing wind followed this axis on the sampling date. As a result the coefficients between the stations A, B and C were

as low as 24.4, 9.3 and 30.4% respectively. The evidence of
the effect of wind upon distribution is demonstrated by
Plate 7, page 113.

    2. Vertical Distribution

        A. Phytoplankton Variation as a Whole

        The study of the vertical distribution of phyto-
plankton species from May to September of 1967 showed some
conspicuous examples of vertical variation in quantity. Fre-
quently the development of this variation was prevented or
short-lived due to wind-mixing. Some examples of vertical
variation in total algal cell counts on different sampling
dates during the study period of 1967 are illustrated by
Table 15, page 114 and Figure 17, page 115. Generally, popu-
lations of different composition showed different types of
distribution. On May 23 the maximum growth of the phyto-
plankton community, of which *Cyclotella meneghiniana* was
dominant, developed in the surface water and a gradual de-
crease in cell numbers took place as the depth increased.
The cyanophycean species *Anabaena circinalis* and *A. spiroides*
var. *crassa*, which are well known for their buoyancy, bloomed
on June 26 which was a calm, sunny day. On this particular
day the accumulation of algal cells was as great as 41,648
cells/ml in the surface water and 25,466 cells/ml at the 2
meter level. Of these numbers the non-cyanophycean cells
accounted for only 1958 cells/ml in the surface water and
4.046 cells/ml in the water at the 2 meter depth. A drastic
decrease in cyanophycean cells took place in the water at

Plate 7. Bloom of *Anabaena circinalis* which accumulated in the
southeast part of the lake as a result of the action
of the northwest prevailing wind, June 21, 1967.

TABLE 15

Vertical Distribution of Total Counts of Algal Cells for

Selected Sampling Dates of 1967

D E P T H (meters)	May 23	June 19	June 26	D A T E S July 17	July 31	August 21	September 5
Surface	48485	24518	41648	4160	25092	4883	8278
1	33558	21325	22066	--	--	--	--
2	33619	--	25466	3130	20622	3468	8299
3	23155	18678	5428	--	--	--	--
4	19319	--	6828	4347	15960	3214	6906
5	20094	12590	6230	--	--	--	--
6	15503	--	6028	2829	19026	2522	3869

Figure 17. Vertical Variation in Total Phytoplankton Cell Numbers for Selected Dates at Station A, 1967

115
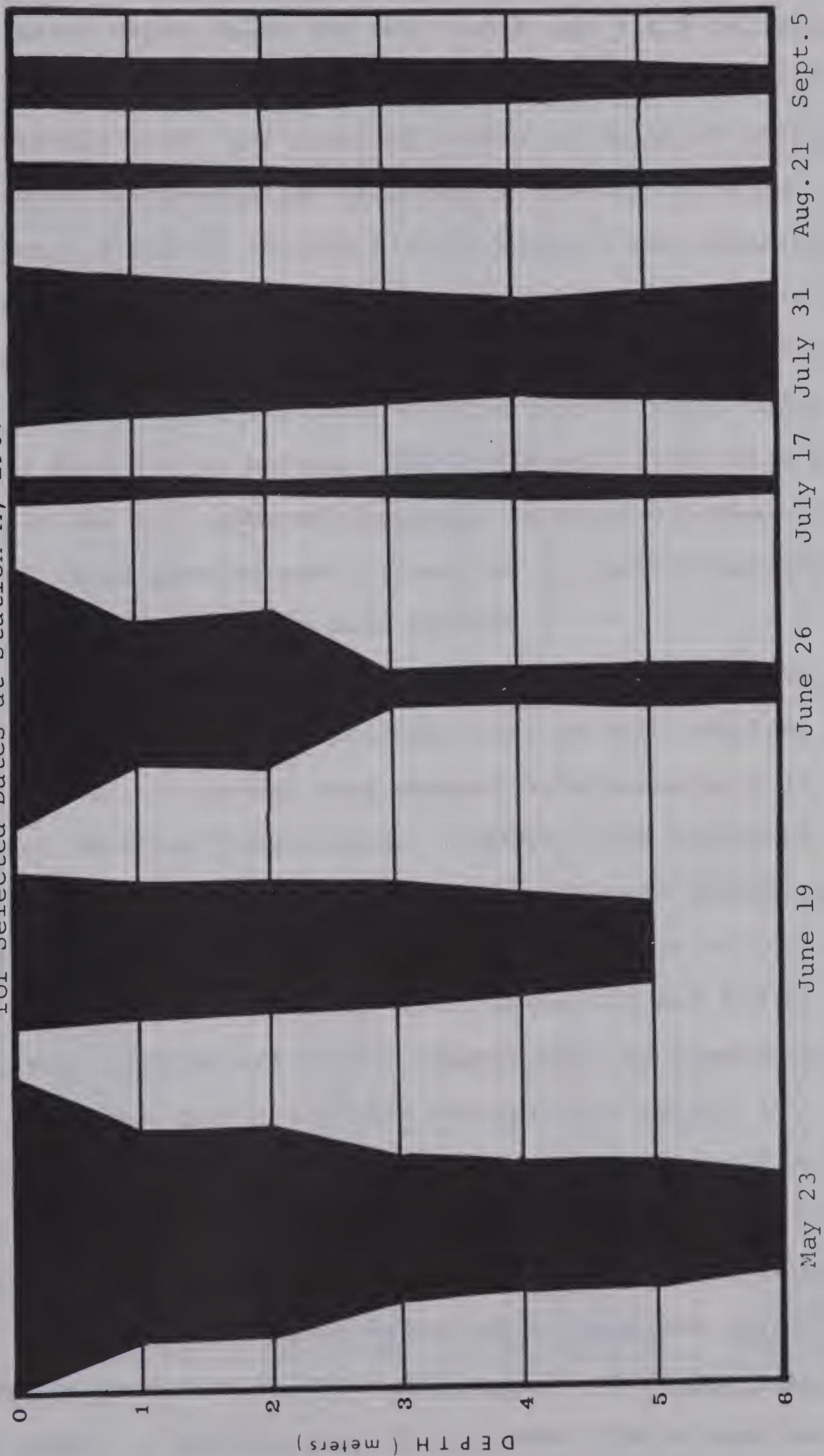
the 3 meter depth where the cell count was 5,428 cells/ml
with the non-cyanophycean species comprising 4,638 cells/ml.
A relatively small and constant number of cells of which very
few were blue-green algae occurred in the depths below
3 meters. A rather uniform distribution of the blooming
Anabaena species occurred on June 19 and July 17 due to the
strong wind-mixing. Data for July 31, August 21 and Septem-
ber 5 show that the vertical distribution of algal cells was
gradual from top to bottom. This type of distribution was
probably due to lack of dominant species of green algae.
None of these species was dominant at any particular depth.

B. Variation of some Species

A superficial examination of the quantitative data
of the planktonic algae indicates that on each sampling date
the majority of species were present heterogeneously in
terms of vertical distribution. However, the degree of
heterogeneity varied considerably at different depths and
times. This irregular change in vertical distribution can
be illustrated by Figures 18 - 21, pages 117 and 118 in
which four species are shown. Examination of Figure 18,
page 117 shows that *Cyclotella meneghiniana* tended to
develop the densest population in the upper layer of vernal
water and was somewhat evenly distributed during its declin-
ing stages. At the end of its seasonal growth the largest
cell numbers of *Cyclotella meneghiniana* appeared at greater
depths in the water column. This type   of distribution
   is also   demonstrated by the other diatom species.

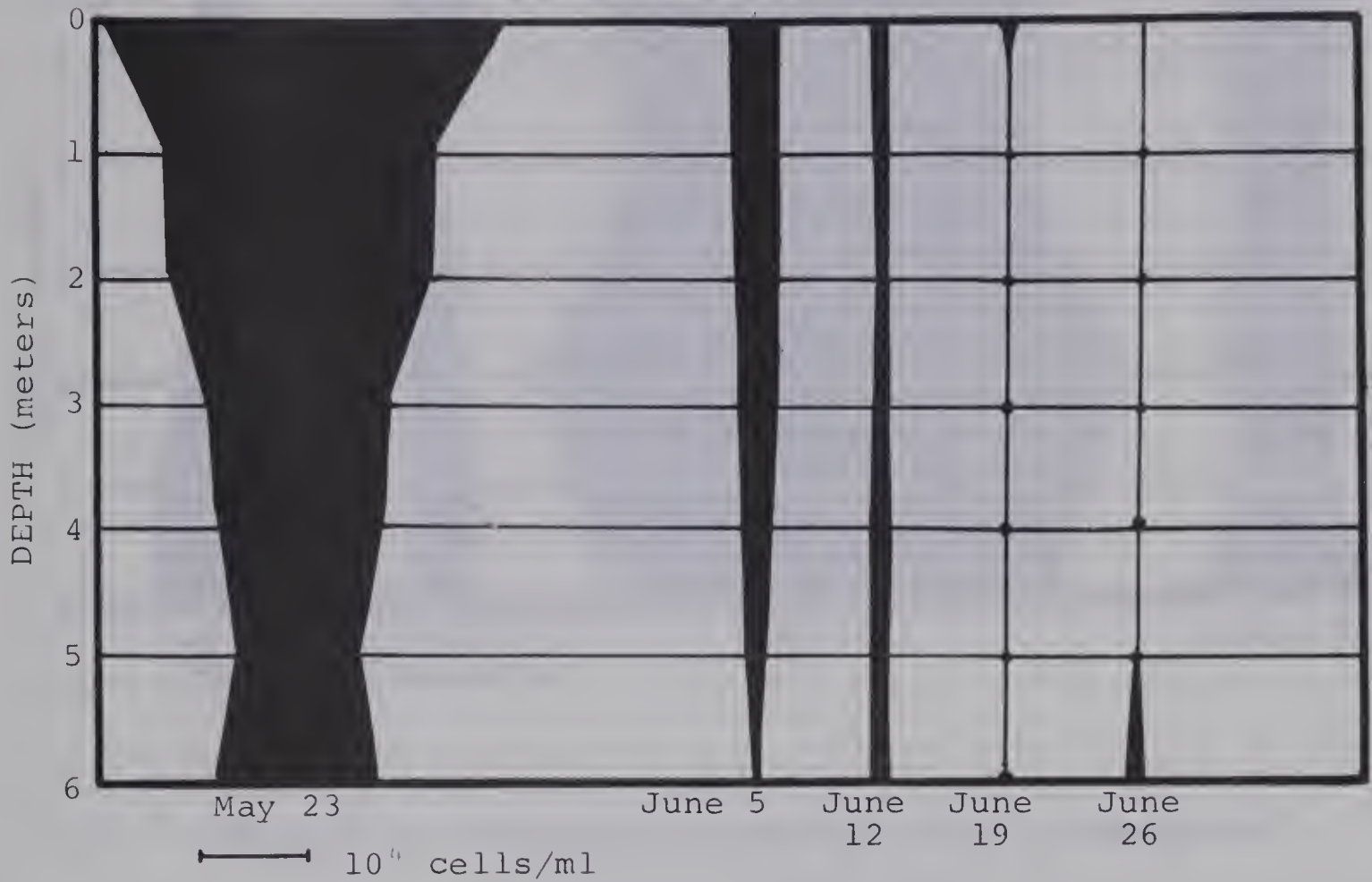Figure 18. Vertical Variation in Cell Numbers of *Cyclotella meneghiniana* for Selected Dates, 1967

Figure 19. Vertical Variation in Cell Numbers of *Melosira italica* for Selected Dates, 1967
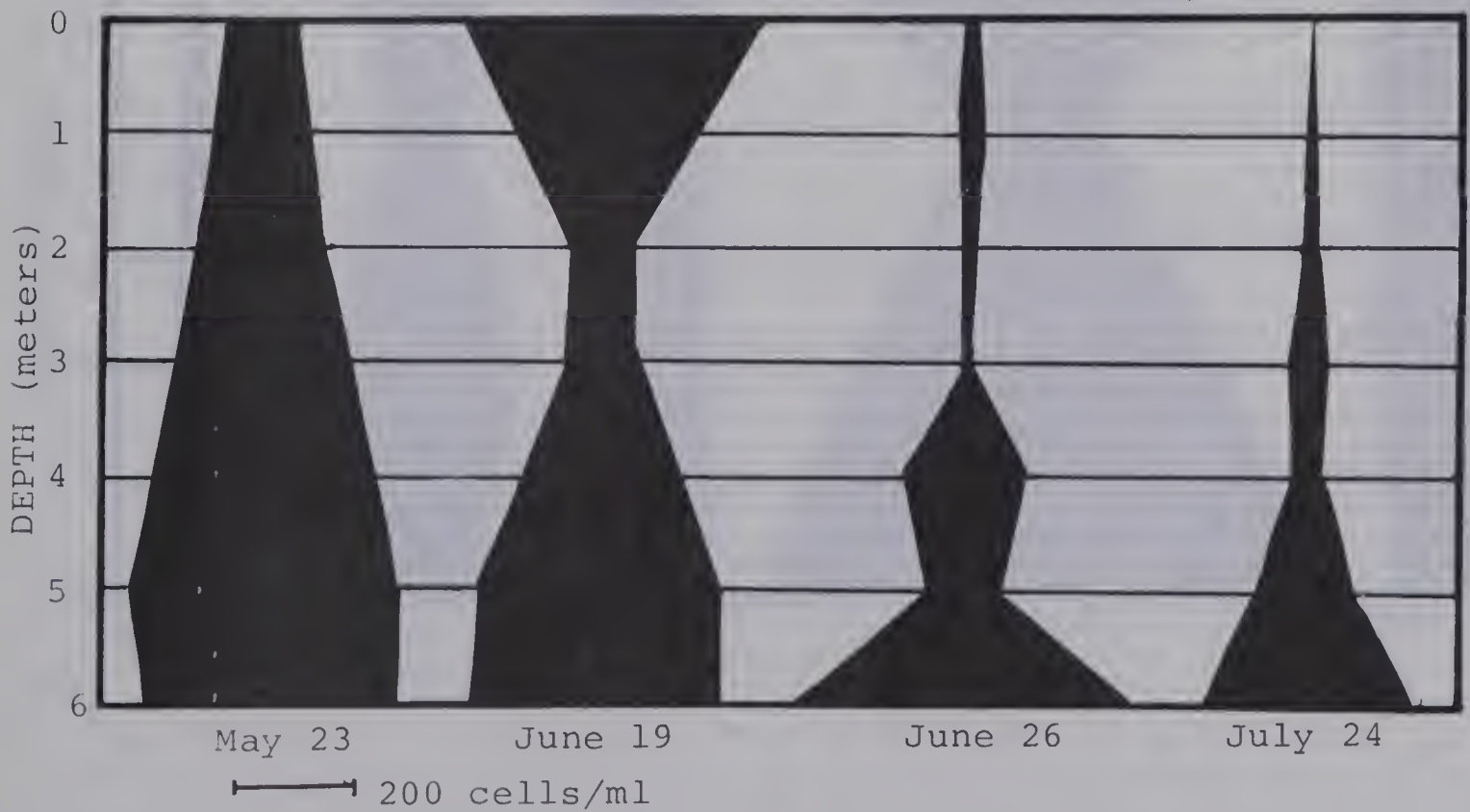
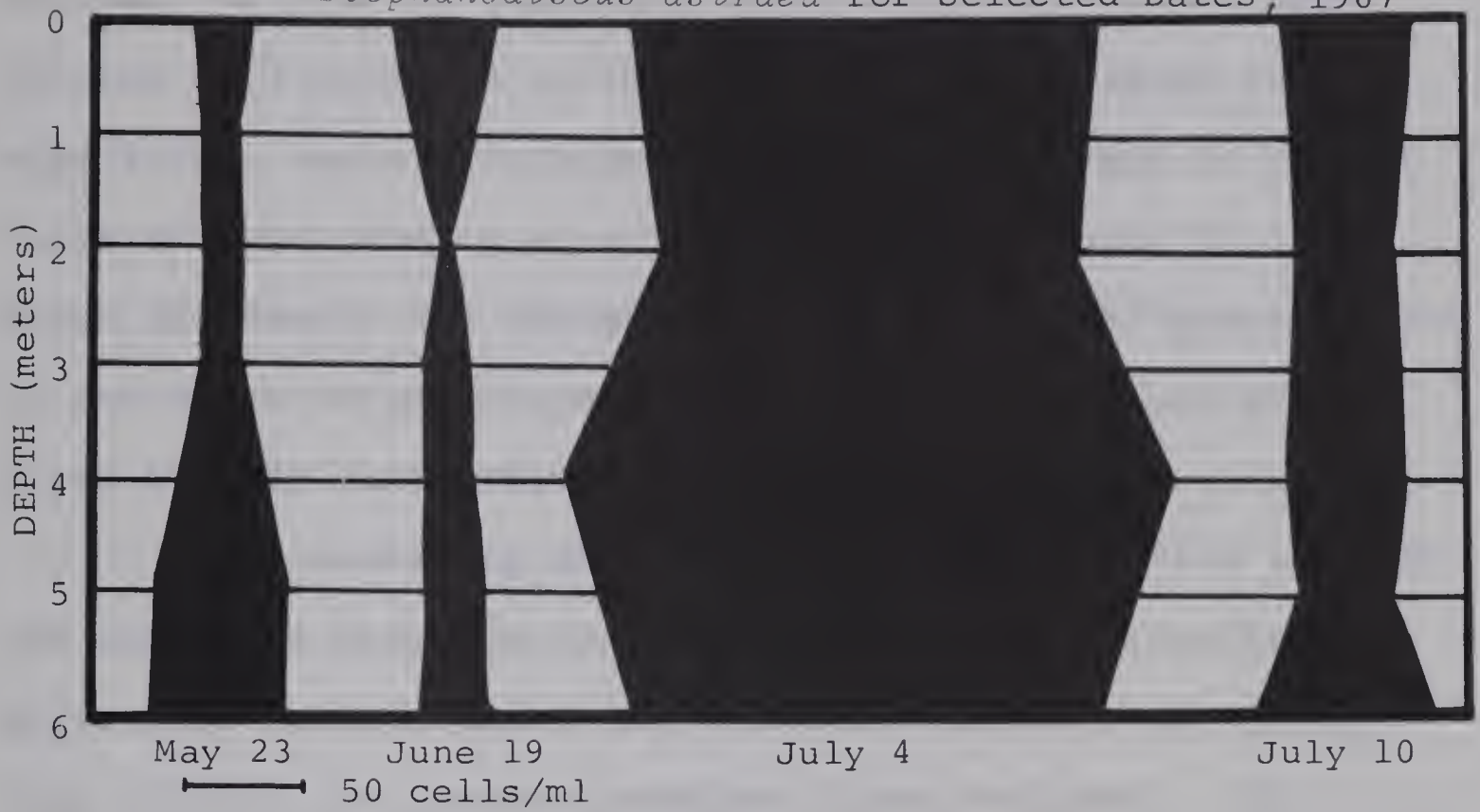Figure 20. Vertical Variation in Cell Numbers of *Stephanodiscus astraea* for Selected Dates, 1967

Figure 21. Vertical Variation in Cell Numbers of *Scenedesmus quadricauda* for Selected Dates, 1967

Melosira italica is an example of a bottom water inhabitant. However, on June 19 unusually large cell numbers for this species were recorded in the surface waters (Figure 19, page 117). Again, windy weather on June 19 seems to be the cause of this unusual situation. *Scenedesmus quadricauda* shows the casual and irregular occurrence at different depths of the water column which is characteristic of most green algae in this lake (Figure 21, page 118).

By examining the cell numbers from surface and bottom waters of many non-cyanophycean species, a remarkable difference between those two water levels was noticed on June 26 when the *Anabaena* maximum bloom occurred. For instance, during the period from June 19 to June 26 the cell counts of *Cyclotella meneghiniana* decreased from 498 to 0 cells/ml on the surface and increased from 541 to 738 cells/ml at the 6-meter depth. Similar fluctuations were recorded for other diatom species such as *Stephanodiscus astraea*, *Melosira italica*, *Synedra acus* and *Navicula* sp. *Nitzschia* sp., however, had a relatively even distribution. Many species of green algae also displayed this bottom accumulation such as *Oocystis* sp., *Scenedesmus quadricauda*, *Tetraëdron muticum*, etc. Two exceptions were *Scenedesmus dimorphus* and *Crucigenia rectangularis* which showed slightly larger numbers in the surface waters than at the bottom.

DISCUSSION

Changes in the components of the plankton flora in Astotin Lake from year to year have been observed. Carefoot (1959) listed seven species of *Pediastrum* and eleven species of *Scenedesmus*, while only three species of *Pediastrum* and six species of *Scenedesmus* were recorded in this investigation. The presence and disappearance of a few minor species were also observed between the years of 1966 and 1967. For instance, *Golenkinia radiata*, *Micractinium pusullum* and *Coelastrum microporum* were recorded in 1967 but not in 1966; while some species such as *Ankistrodesmus falcatus*, *Quadrigula lacustris* and *Gloebotrys limneticus* were recorded in 1966 only. Such changes in plankton flora are associated, I believe, with algal control by use of great amounts of algicides such as copper sulfate and phygon during 1964 and 1965 (more than 5,000 pounds per year). The susceptibility of various common plankton algae to copper sulfate has been tested by Palmer (1962). Phygon is reported to be particularly toxic to blue-green algae (Fitzgerald et al 1952). Palmer and Tarzwell (1955) pointed out that the growth of certain species of algae was favoured by the treatment of the water with copper sulfate. For instance, species of *Ankistrodesmus*, *Pediastrum* and *Scenedesmus* were stimulated to multiply by copper sulfate concentrations of 0.5 ppm. In the Astotin Lake studies it was found that the physical conditions such as temperature and light intensity, and the

chemical conditions such as nitrate and pH remained fairly constant from 1966 to 1967. Therefore, I think that the treatment with algicides in 1965 affected species diversity according to the susceptibility of those species present.

A notable variation in the diatom dominants such as *Asterionella formosa* and *Cyclotella meneghiniana* of the spring phytoplankton community occurred in 1966 and 1967. A sizeable population of *Asterionella formosa* occurred as a vernal pulse (2,405 cells/ml) in 1966, but this species was absent in 1967. Pearsall (1932) pointed out that *Asterionella* was a diatom developing best in waters rich in nitrates, phosphate and silicon, and he mentioned that substantial increase in population did not take place in these waters if silica was below 0.5 ppm and that the lower limit of phosphate was 0.002 ppm. In 1967 the silica concentration in Astotin Lake was recorded as 0.85 ppm and the dissolved phosphate was present as 0.3 ppm on May 18, 1967. It is unlikely that failure of *Asterionella formosa* to develop in this early spring water was caused by a low level of nutrients. An important point in connection with the disappearance of *Asterionella* in 1967 is the problem of vitality during its resting stage. In examination of many mud samples after the maximum growth of *Asterionella* in 1966 there was no evidence of the presence of "resting spores" except some detatched cells with disintegrating chromatophores. A similar lack of resting forms for *Asterionella* was observed in England by Lund (1949). However, this lack of distinctive resting cells

by no means indicated that *Asterionella* has no dormant stage
in the lake. Like many other species of plankton diatoms,
such as *Tabellaria*, *Fragilaria* and *Melosira*, *Asterionella*
may pass its dormant stage as vegetative cells. However,
Lund (1949) found that under both field and laboratory con-
ditions the vegetative cells of *Asterionella* died if oxygen
depletion occurred. In view of Lund's report, probably the
best explanation for the disappearance of *Asterionella* in
Astotin Lake during 1967 is the oxygen depletion during the
ice cover period of 1967.

The occurrence of *Dinobryon sertularia* in Astotin
Lake is of interest. No sign of this species was observed
in 1966, while it appeared abundantly for a short period dur-
ing the early summer of 1967. The species *D. divergens* has
been studied intensively by a number of investigators.
Pearsall (1932) pointed out that the maximum of *D. divergens*
occurred when the SiO_2 content of the water fell below
0.5 ppm. In Astotin Lake *D. sertularia* occurred in 1967 when
the silica concentration ranged from 0.08 to 0.1 ppm. In the
same period of time of 1966 the silica content was between
3.5 to 7.0 ppm. But Hutchinson (1944) found that the appear-
ance of *Dinobryon divergens* in Linsley Pond was independent
of variations in soluble silicate. According to Bozniak
(1966) in Muir Lake the maximum number of cells of this spe-
cies occurred when the silica concentration was recorded as
1.45 ppm which is much above Pearsall's critical limit, and
the range in Astotin Lake. Besides silica, phosphate is the

other important factor which has been connected with the
occurrence of *Dinobryon*. Rhode (1948) found that in culture
Dinobryon divergens was inhibited when the phosphate concen-
tration rose to 0.005 ppm. However, in Astotin Lake *D.
sertularia* occurred when the phosphate was recorded in a
range of 0.2 to 0.4 ppm. Bozniak (1966) reported that in
Muir Lake the *Dinobryon* was initiated when the phosphate
was nil and reached its maximum when phosphate was near 0.3
ppm.

Although the occurrence of *Dinobryon divergens* is
hard to attribute directly to any known chemical variation
in these investigations, nearly all of the papers recorded
that the rise in *Dinobryon divergens* occurs after a rapid
decline of large populations of other antecedent species.
In Astotin Lake *Dinobryon sertularia* occurred in a similar
pattern. This species was present in early June of 1967 and
its maximum occurred when the spring maximum of *Cyclotella
meneghiniana* declined and the summer bloom of *Anabaena* had
not yet begun. In view of the pattern of occurrence of
Dinobryon, it seems most likely that the population is sup-
pressed by a maximal spring population of other planktonic
algae such as diatoms and that *Dinobryon* can increase its
population at lower nutrient levels when other competing
algae have declined. Hutchinson (1944) concluded that the
incidence of the *Dinobryon* maximum is probably determined by
biotic rather than physiochemical factors.

In temperate waters where spring and fall turnover

occurs, the development of the phytoplankton is closely
related to these events. Many studies show that the spring
maximum of phytoplankton starts from a small initial number
of cells after spring turnover. These populations are most
often initiated either from cells of a species in the water
or from cells of a species in the resting stage on the bot-
tom deposits and absent from the water. Fogg (1965) des-
cribed these two kinds of planktonic algae as holoplanktonic
and meroplanktonic, respectively. In Astotin Lake the results
show that the first phytoplankton maximum of the season in
1966 was caused by *Asterionella formosa* which is considered
to be an example of the holoplanktonic type (Lund 1949).
This maximum was recorded at the end of May in 1966 when the
study began, one month after the ice break-up. It is likely
that the "true" spring maximum in 1966 occurred shortly after
the ice melted when the water temperature, light intensity
and dissolved nutrients were favorable to planktonic algal
development. The observations in 1967 strongly support this
supposition. In 1967 the spring maximum caused by *Cyclotella
meneghiniana*, which is classified as a meroplanktonic species,
took place at the end of May, which was the second week sub-
sequent to the ice break-up. However, it is hazardous to draw
any conclusions on the annual variation in species composition
and seasonal succession in any given lake without a long-term
investigation.

The decline of diatom populations may be due to
various factors. The deficiency of mineral nutrients would

be expected to be one of the most important factors, but studies involving effects of deficiency for most nutrient elements are not conclusive. Silica is probably the only one for which studies show rather clear agreement between laboratory and field observations. According to the investigations of Pearsall (1932), Lund (1950) and Jørgensen (1957), the close of spring maxima for diatoms is caused by the silicon deficiency of the water. However, Rodhe (1948) and Golterman (1960) report that the combination of strong light and high water temperature is also a factor in the dying off of the diatoms. In Astotin Lake the silica content of the water was exhausted by the end of May and the water temperature began to rise early in June. It may be concluded that these two factors were chiefly responsible for the decline of these diatom spring maxima, which were caused mainly by *Asterionella formosa* in 1966 and *Cyclotella meneghiniana* in 1967.

The seasonal cycle of diatoms is always associated with recycling of dissolved silica in a lake. Grill and Richards (1964) studying the nutrient regeneration from dead diatoms found that it began following the eighth day, and that 95% of silica was redissolved within six months. However, the availability of the soluble silica in the surface water is dependent upon the depth of the water. Jørgensen (1957) reported that in shallow lakes soluble silica appeared again in great quantity in the water only a few weeks after the maximum of planktonic diatoms. In Astotin Lake the silica concentration increased to 0.7 ppm at the end of June

1967, a month after its depression. However, the availability of large quantities of dissolved silica in this lake throughout the summer did not cause any striking production of planktonic diatoms. The development of large populations of planktonic diatoms may be impeded by high water temperature and inhibited by the blue-green algal blooms during the course of summer. As expected, the diatom pulse reappeared in the fall when the water temperature decreased and blue-green algae had declined.

Phytoplankton studies of many lacustrine systems in temperate areas suggest that the pattern of seasonal development of phytoplankton shows maxima in the spring and the fall and minima in the early summer and winter. Fogg (1965) stated that during the summer period, following the spring maximum, there is normally a period of two months or so in temperate lakes and seas when the standing crop of phytoplankton remains at a relatively low and steady level. This low level is attributed to the depletion of nutrients from the photic zone by the sedimentation of the greater part of the cells produced in the spring maximum, and thermal stratification stabilizing the water column so that there is no nutrient replenishment by mixing from the hypolimnion. However, as in many other shallow lakes, the condition of thermal stratification is poorly developed in Astotin Lake during the summer, and the picture of phytoplankton periodicity is quite unlike that of deep waters. In this lake constant circulation of the whole water column prevents the nutrients from being idled

by sedimentation and the regeneration of nutrient from dead
algal cells is a concurrent process. Watt and Hayes (1963)
have estimated the turnover times in inshore waters off Hali-
fax, Nova Scotia as one and one-half days for dissolved in-
organic phosphorus, two days for particulate phosphorus, and
half a day for dissolved organic phosphorus. In the case of
autolysis under sterile conditions Golterman (1960) found
that 70 - 80% of the element phosphorus leaves the dead
Scenedesmus cells within a few days. The chemical results of
the present study indicated that nutrient depletion, except
for silica, did not occur during the period following the
spring pulse of phytoplankton. After the decline of the dia-
tom pulse in early June the blue-green algal blooms developed
and were present until late summer. The sequence of blooms
in Astotin Lake during 1966 was *Microcystis*, *Aphanizomenon*
and finally *Microcystis*. In 1967 the sequence was *Anabaena*
a mixture of *Aphanizomenon* and *Microcystis*, and lastly
Microcystis.

      The development of *Anabaena* was not intensive in
1966 and it bloomed immensely in the early summer of 1967.
According to Hammer (1965), in many Saskatchewan lakes the
Anabaena blooms occurred when the lower limit of T.D.S. was
423 ppm. High organic matter in the water was also reported
as an important factor to induce blue-green algal bloom
(Pearsall 1932, Vance 1965). In Astotin Lake the T.D.S. was
recorded as 228 ppm and dissolved organic matter was 21 ppm
on June 7, 1966. During the same period of time in 1967,

the figure for T.D.S. was 400 ppm and for organic matter 84
ppm. The relatively, much lower T.D.S. and organic matter
content of the water in 1966 was likely due to water treat-
ment with algicide in the previous years. The algicide had
reduced the production of algal cells, which in turn dimin-
ished the addition of nutrients which are derived from the
breakdown of algal cells in the water. A spectacular bloom
of *Anabaena* occurred early in the summer of 1967, when the
concentration of the nutrient elements was relatively
favorable for bloom development. At this time the water tem-
perature increased to a range of 15°C to 21°C. The intensive
bloom of *Anabaena* developed to its maximum on June 26 and a
decline followed, although the nutrient level of most elements
remained more or less constant. However, the dissolved phos-
phate and the water temperature changed drastically. The
decline of the maximum *Anabaena* bloom was associated with a
low phosphate concentration which dropped from 0.35 ppm to
0.02 ppm, and high water temperatures which increased from
16.0°C to 21.4°C within a week's period (between June 19 and
26). The decline of *Anabaena* bloom extended over three weeks
as a lag stage when the water temperature ranged from 17 -
19°C and it crashed on July 24 when the water temperature was
recorded as 21.4°C. The *Anabaena* bloom formed when the tem-
perature was above 15°C and declined when the temperature
rose above 21°C.

        In addition to the deficiency of nutrient elements
and high water temperatures a possible cause of the decline

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of *Anabaena* bloom may have been the accumulation of extra-
cellular products released from *Anabaena* cells as an inhibi-
tor to themselves. Vance (1965) pointed out that the sudden
"crash" of a single cyanophycean bloom may be due to an active
metabolite produced by the blooming species.

Anabaena plays an important role in the nitrogen
cycle of lakes because of its ability to fix atmospheric nit-
rogen. Although nitrogen fixation by *Anabaena* species has
been well documented, the process of nitrogen regeneration
in situ from dead cells is still not clear. Grill and
Richards (1964) observed the release of ammonia from dead
algal cells. Theoretically, nitrogen should be present as
nitrate in the water through the process of nitrification
when dissolved oxygen is present in abundance. In Astotin
Lake the chemical tests showed that no nitrate was detected
throughout the entire study period, except for a record of
2.6 ppm on December 20, 1966. This high concentration of
nitrate in the early winter is no doubt a result of the de-
composition of algal cells from the populations of the pre-
vious fall. Presumably, the nitrogen was present as a re-
duced form (NH_4^+) under the ice when the dissolved oxygen
was low in late winter. Billaud (1967) reported that when
N^{15} was used to measure the nitrogen uptake by *Anabaena*
ammonia is the predominant form being taken up. Earlier,
Syrett (1962) showed that most algae with chlorophyll can
apparently utilize either ammonia or nitrates when these are
available, and that ammonia is often used preferentially

when it is supplied together with nitrate. Thus, I think that the disappearance of nitrate in Astotin Lake during the growing season is most likely caused by the plankton algae which completely used the nitrogen released from the dead cells in the form of ammonia. However, the measurement of ammonium nitrogen present in the water is necessary to support this explanation.

Prowse and Talling (1958) reported that the *Anabaena* bloom was an important factor in determining the seasonal succession of planktonic algae. Bilaud (1967) pointed out that a bloom of *Anabaena* during the low nitrogen period following impoundment was followed by a population of algae which were apparently using nitrogen regenerated from the nitrogen fixed by the initial population of blue-green algae. This report not only confirms the possible importance of nitrogen-fixing blooms of algae, but suggests that nitrogen assimilated into an algal population can become available rather quickly to a subsequent population, presumably as a result of the release of ammonia upon the death of the cells. In Astotin Lake, following the disappearance of the *Anabaena* bloom in 1967, a tremendous increase of green algae both in species diversity and population sizes, accompanied by blooms of other species of blue-green algae followed. This interesting development was closely associated with the event of the *Anabaena* bloom.

Shortly after the *Anabaena* pulse declined in Astotin Lake, *Microcystis* and *Aphanizomenon* produced the

mid-summer water bloom. During 1966 the bloom of *Microcystis* and *Aphanizomenon* occurred mainly in July and disappeared in the late summer. In 1967 the bloom caused by *Microcystis* and *Aphanizomenon* developed intensively in August and *Microcystis* extended to September. Hammer (1964) reported that *Microcystis* bloomed when the water temperature was above 20°C and *Aphanizomenon* bloomed when the temperature was above 22.5°C. When the water temperatures in Astotin Lake are examined, it can be seen that the warmest month of 1966 was July with a range of 18 - 24°C, while in August the temperature was constantly below 19°C. In 1967 a different series of water temperature was recorded. This year the water temperature was constantly above 19.5°C from late July until early September. The water temperature and occurrence of these algal blooms coincided closely with the pattern Hammer found in Saskatchewan lakes. Therefore, we may conclude that water temperature influences the time of appearance and the sequence of bloom formation.

The dominance of blue-green algal blooms in the community succession of blue-green algae has been always associated with the development of a single species. (Prescott 1960, Vance 1965). However, in Astotin Lake the blooms showed a mixture of *Aphanizomenon* and *Microcystis* in August of 1967, although these species were not dominants at the same period of time. *Aphanizomenon flos-aquae* reached its peak production when the water temperature increased to nearly 23°C and declined rapidly in a week or so in mid-August when the water temperature decreased. This

disappearance of *Aphanizomenon* was probably caused by the decreasing water temperature and by its incompatibility with *Microcystis* which forms a bloom in a wider temperature range. During the period of intense blooms the process of degeneration of dead algal cells and the multiplication of new colonies of these bloom species occur simultaneously, so that the identification or quantitative estimation of the active cells is extremely difficult.

A great deal of information dealing with the phenomenon of fluctuations of green algal populations and the relationship of these fluctuations to the chemical and physical factors of the environment is available. In various bodies of water the factors of nutrient level, temperature and light have been found to affect green algal development differently. For instance, Rodhe (1948) found that in his cultures the green algae such as *Scenedesmus*, *Ankistrodesmus* and *Coelastrum* grew best at temperatures of 20 - 25°C, but McCombie (1953) pointed out that these green algae may flourish in the lake of lower temperature. Rodhe also stated that "concerning *Scenedesmus quadricauda*, I can confirm the common conception that magnesium and potassium should not be counted with the factors which limit algal development in the lakes." However, McCombie (1953) pointed out that the importance of magnesium and potassium in phytoplankton production is too often underestimated. I consider that the compatibility of green algal species in the presence of certain blue-green algae is more important than any other environmental factor in

controlling the fluctuation in green algal populations.

Hartman (1960) found that the growth rates in culture of cer-

tain species of *Scenedesmus* and *Dictyosphaerum* were doubled

after adding the extracted water which was taken from a

reservoir at the end of the summer bloom caused by *Micro-*

cystis aeruginosa. Prescott (1960) stated "if one allows

a plankton collection dominated by *Aphanizomenon* to stand in

the laboratory for a time, *Ankistrodesmus*, *Pediastrum* and

Oocystis will flourish after the dominant has died. As long

as the *Aphanizomenon* is alive, it completely inhibits develop-

ment of the other plankters." From the results of the sea-

sonal studies of green algae in Astotin Lake, I concluded

that species composition and population growth were closely

related to the succession of water blooms during the summer.

During the course of an *Anabaena* bloom the species diversity

of green algae was appreciably decreased and most of these

species were present in extremely small numbers. However,

Scenedesmus quadricauda exhibited a compatible reaction to

the bloom of *Anabaena spiroides* var. *crassa* and an antagonis-

tic reaction to *Microcystis aeruginosa*. Controversially,

Bozniak (1966) pointed out that the growth of *Scenedesmus quad-*

ricanda was inhibited during the bloom of *Anabaena flos-aquae*.

        During late July of 1967 the chlorophycean commun-

ity increased threefold in species numbers and almost five

times in cell numbers within one week after the *Anabaena*

bloom disappeared. This most striking development of green

algae, in both species diversity and individual numbers,

likely was stimulated by the breakdown substances from the dead cells of *Anabaena spiroides* var. *crassa* and *A. circinalis*. The phenomenon of severe oxygen deficit on July 24 was good evidence of intensive decomposition during that period of time. The present study provides further evidence that the *Anabaena* bloom affects the sequence of summer blooms as well as the succession of other phytoplankton.

In an attempt to obtain more accurate estimates of phytoplankton abundance and species composition in any sizeable lake, the possible variation in both horizontal and vertical distribution should be considered. The horizontal variation in phytoplankton distribution is basically due to the variation in temperature and concentrations of available nutrients at different locations in a lake. Mechanical features such as seiches, prevailing winds, inlets and outlets of the lakes also have an important effect upon the horizontal variation of planktonic algae. After reviewing a number of publications on the horizontal distribution of lake plankton, D'Ancona (1955) concluded that a sure documentation indicated the irregular distribution of lake plankton and that the idea of homogeneous uniform distribution can no longer be sustained. Rawson (1956) investigated Great Slave Lake and found that the variation in plankton crop at different locations was caused by variations in temperature, turbidity and edaphic (mineral) conditions. Mortimer (1952) gave an exhaustive description of wind-induced movements in bodies of water and the effect of the internal waves on

plankton distribution. In Astotin Lake, which posseses a relatively uniform basin and small area with no significant drainage system, the horizontal distribution of phytoplankton was predominantly affected by wind action. The degree of dissimilarity of phytoplankton abundance between stations was determined by the overall density of the plankton crop and the direction and strength of the wind. However, the regional occurrence of *Gloeotrichia echinulata* was likely associated with the thick vegetation of *Scirpus validus*. No information is available to explain the case of *Dinobryon sertularia* which occurred in abundance in the northwest part of this lake but was extremely rare in other areas.

As far as the vertical distribution of the planktonic algae in a lake is concerned, the vertical variation in water temperature and light penetration should be taken into account first, in temperate, deep lakes. Ruttner (1963) used Seneca Lake in North America as an example. He pointed out that 99% of the total radiation was absorbed within the upper 10 meters in which there was no appreciable difference in temperature. Theoretically, the investigation of vertical variation in planktonic algae in water which is less than 10 meters deep is meaningless in terms of the effect of solar radiation and water temperature. The present studies indicate that species of most blue-green planktonic algae are primarily surface water forms and that their dense growth influences the light penetration a great deal. This would cause the vertical variation in the species of blue-

green algae as well as the variation in the associated spe-
cies, even in this shallow water. In Astotin Lake this type
of vertical distribution occurred transitorily in calm
weather. The diatoms such as *Melosira* and *Stephanodiscus*
tended to be "bottom dwellers" when the summer blooms occurred.
The abundance of most of the green algae varied at random
throughout the water column. No species, except blue-green
algae, showed definite characteristics of vertical distribu-
tion in this study.

Since there is a long ice-cover period in the lake,
the question arises as to the survival of resting spores or
vegetative cells of blue-green algae during the severe win-
ter. A culture experiment was designed to test the low tem-
perature effect on the resting cells of *Anabaena*, *Microcystis*
and *Aphanizomenon*. The cells used were collected from the
bottom water and the surficial mud during the summer. The
method used in treatment and culture of the cells is described
on page 29 - 30. The results of my culture study showed
that *Anabaena* colonies grew vigorously in all cultures both
on agar plates and in nutrient solution but *Microcystis* and
Aphanizomenon were absent from these cultures. According to
Dr. Lang (personal communication) the untreated cells of
these species of blue-green algae can be cultured easily in
solution medium, and *Anabaena* grows well on agar plates.
Wolk (1952) has cultured and observed the heterocysts of
Anabaena. The absence of *Aphanizomenon* and *Microcystis*
in my cultures may be due either to the destruction of the

dormant cells by low temperature treatment or to the fact that

the multiplication of these cells in the cultures was too

feeble to be detected. Further information is required before

giving a conclusive answer to this question of the survival

of blue-green algal cells at low temperature.

The main objective of this investigation, which

was initiated by the administration of Elk Island National

Park, was to find a means of controlling the summer water

blooms. I have found that the development of algal blooms

in this particular lake is too complex a process to be con-

trolled by any easily applied treatment. Continuous treat-

ment of Astotin Lake with algicide was carried out for

quite a few years before 1966. The efficiency of this treat-

ment was not clearly documented, but the bloom in 1966 indi-

cated that the chemical treatment used is definitely a poor

method for controlling blooms in this lake over a period of

time. The high calcium carbonate content of the water causes

the low efficiency of copper sulfate as an algicide because

the $CuSO_4$ is quickly precipitated as copper carbonate.

Furthermore, the great disadvantage of the application of

chemicals toxic to algae for the purpose of controlling

blue-green algal bloom in lakes is the effect of these com-

pounds. It has been shown that frequently the predominant

bloom species would be greatly reduced in cell numbers but

some previous minor species would then multiply rapidly and

become the excessive algal growth of the future. Obviously,

this undesirable effect has resulted from the addition of

available nutrients derived from the breakdown of the dead cells of destroyed algae populations. The record of Astotin Lake strongly indicates that the blue-green algal blooms have been stimulated by the algicide treatments.

Artificial aeration of lake water has been shown to be successful in controlling algal blooms by diversion of eutrophication of a number of deeper lakes in which oxygen depletion in the hypolimnion and thermal stratification occur. However, this method would not be practical in Astotin Lake since oxygen depletion and thermal stratification are rare.

Nitrogen and phosphorus could also be reduced or removed from the water by precipitation. The approach has been used in the treatment of waste water effluents which are the cause of eutrophication of certain particular lakes (Edmonson 1966, Fruh 1967). However, in Astotin Lake the derivation of the nutrients present in the water is so complex that reduction by precipitation involving addition of chemicals to the lake does not seem economical.

In the process of eutrophication in Astotin Lake nutrients are derived mainly from watershed runoff, precipitation, aquatic macro- and micro-vegetation and large population of waterfowl. Little can be accomplished directly in the reduction or removal from the lake water of nutrients derived from the watershed and waterfowl. However, blue-green algae are well known for their ability to accumulate large quantities of nitrogen, phosphorus and organic compounds in their cells (Gerloff et al 1954, Prescott 1960). Therefore,

removal of the cells from surface water during the maximum
bloom of blue-green algae on the dates when high winds cause
the bloom scum to accumulate in a lee shore should be worth-
while. A large amount of nitrogen and phosphorus stored in
these algal cells could be removed in this way. Removal of
dense shore macrophytes can also reduce the nutrients which
become available for recycling in the lake.

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